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DENVER
GREEN CONTINUUM
STREETS GUIDELINES

DENVER
TRANSPORTATION &
INFRASTRUCTURE

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INFRASTRUCTURE

AUTHORED BY:

Office of Green Infrastructure - Denver Department of Transportation & Infrastructure

SPECIAL THANKS TO:

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PROJECT TEAM:

stream
landscape architecture + planning

Matrix
Excellence by Design

MULLER
ENGINEERING COMPANY

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Chapter ONE

INTRODUCTION & VISION

01 - INTRODUCTION AND PURPOSE

Over the past five years, the City and County of Denver has amplified its use of green infrastructure (GI) to manage stormwater, cool city streets, create more equitable neighborhoods, and provide safer connections for bicyclists and pedestrians. By adopting the best practices outlined in ***Denver's Ultra-Urban Green Infrastructure Guidelines***, capital projects are increasingly weaving valuable natural processes back into urban streets by installing green infrastructure.

This guide, the ***Denver Green Continuum: Streets*** *(Continuum: Streets)* guidelines, builds upon this work in hopes to expand the extent and rate of implementation of green infrastructure, in large part, to mitigate and adapt to our increasingly changing climate. In Colorado, climate change is responsible for varied precipitation patterns, warmer temperatures, more intense wildfires, and poorer air and water quality. Climate models project that the average temperature will increase by 2.5°F to 6.5°F by 2050[1] which will continue to exacerbate environmental and public health problems. To mitigate these impacts and protect Denver's high quality of life, green infrastructure needs to be implemented on a greater citywide scale.

Continuum: Streets aims to provide a more robust, versatile and practical set of GI tools and solutions that are more applicable to all types of city streets and conditions. The *Continuum: Streets* focuses on strategies that can manage stormwater and cool city streets while providing additional co-benefits. The *Continuum: Streets* defines five levels of green that range from simply adding vegetation with proper growing conditions to streetscapes, to planting trees in sunken landscapes, to fully engineered stormwater quality planters that store regulatory water quality volumes. By offering a greater suite of green infrastructure practices, Denver can more rapidly implement green infrastructure solutions.

Continuum: Streets is a companion document to the recently adopted *Denver Complete Streets Design Guidelines*. Together these documents detail how streets can be designed to meet current and future needs. While this document focuses on streets and the public right-of-way, the practices detailed within can be put into practice in both public and private spaces.

02 - THE CHANGING CLIMATE

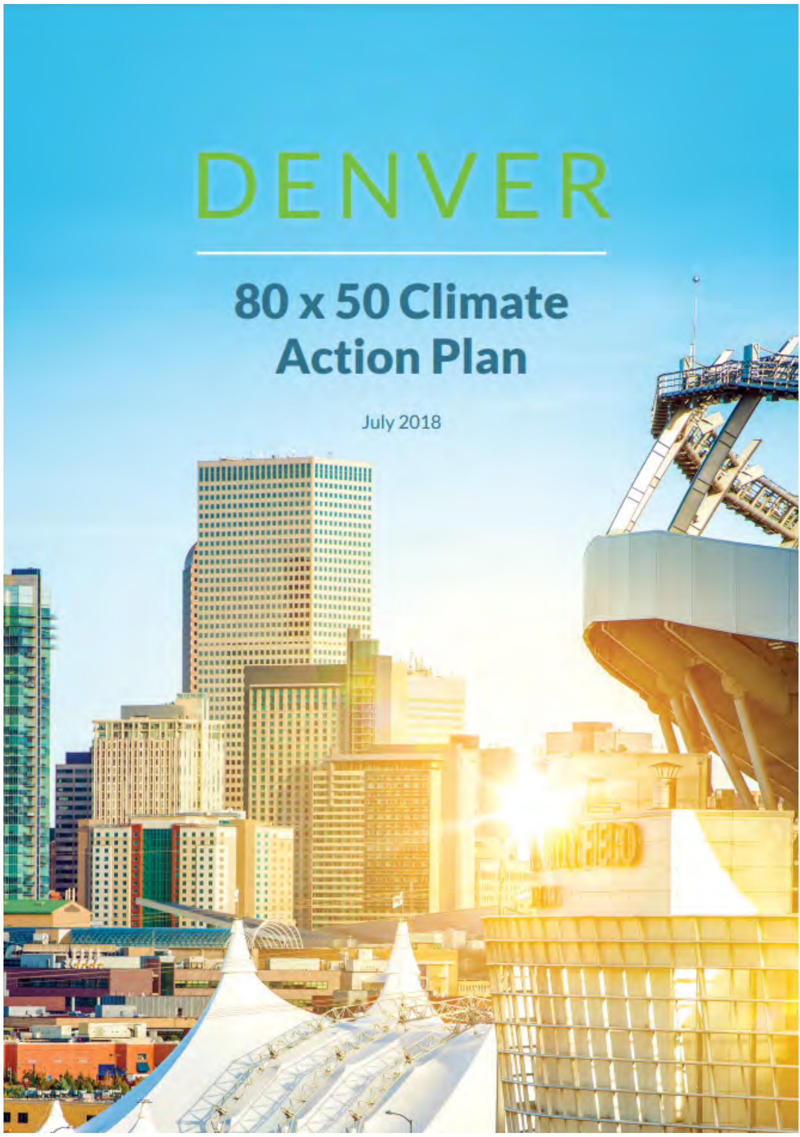
2020 was the second-hottest year on record for the planet and was 1.76 degrees hotter than aveaarage tempature over the last 125 years (NOAA)[2]. The northern hemisphere saw the hottest year on record at 2.30 degrees above average. Most of the increase has occurred since the 1970's and the most recent decade was the nation's warmest in history [3].

The United States, like many places throughout the world, has warmed due to climate change. In Denver, between 2010 and 2020, the average mean temperature has increased 1.1 degrees according to NOAA[4], and climate change models unanimously project further temperature increases in the decades to come. Evidence unequivocally shows that the climate change is happening now and that human-produced emissions of greenhouse gases (GHG) is the primary driver. Because cities generate more than 70% of the greenhouse gas emissions globally, cities have a responsibility to lead the efforts to reduce emissions. In the 80x50 Climate Action Plan (see Figure 1.02.1), Denver outlines strategies for buildings, electricity generation and the transportation sector to reduce GHG emissions by 80% by 2050.

Many of these strategies will require significant investments and a great deal of time to achieve. In the meantime, green infrastructure is a powerful, readily available, cost-effective tool in adapting to and mitigating the impacts of a changing climate.

02.1 - ENVIRONMENTAL HEALTH IMPACTS OF A CHANGING CLIMATE

The environmental impacts from the changing climate are diverse and serious and threaten Coloradoans' way of life. An increase in extreme weather events and temperature will have far reaching, interconnected and detrimental consequences on the environment and ecosystems on which we depend.



DENVER

80 x 50 Climate Action Plan

July 2018

Figure 01.02.1 : City of Denver 80x50 Climate Action Plan

EXTREME STORM EVENTS

Climate change models forecast more frequent and intense storm events followed by prolonged periods of drought in Colorado. Recent projections suggest that heavy storms (storms of one half-inch of precipitation or more in a day) may also become more frequent. Emission scenarios project that these storms will become anywhere from 15-25% more likely by mid-century and 17-31% more likely by the end of the century[5]. While these projections have somewhat large ranges, the primary hydrological impact modelers are predicting for Colorado's future climate is major precipitation variability with some years wetter than normal and others bringing severe drought-like conditions.

Over the last decade, devastating floods and fires occurred along with Colorado's most expensive hailstorm to date in 2017. A bomb cyclone hit the state in March 2019 and became the strongest storm recorded in the state's history[6]. In 2020,the Cameron Peak Fire, East Troublesome Fire, and the

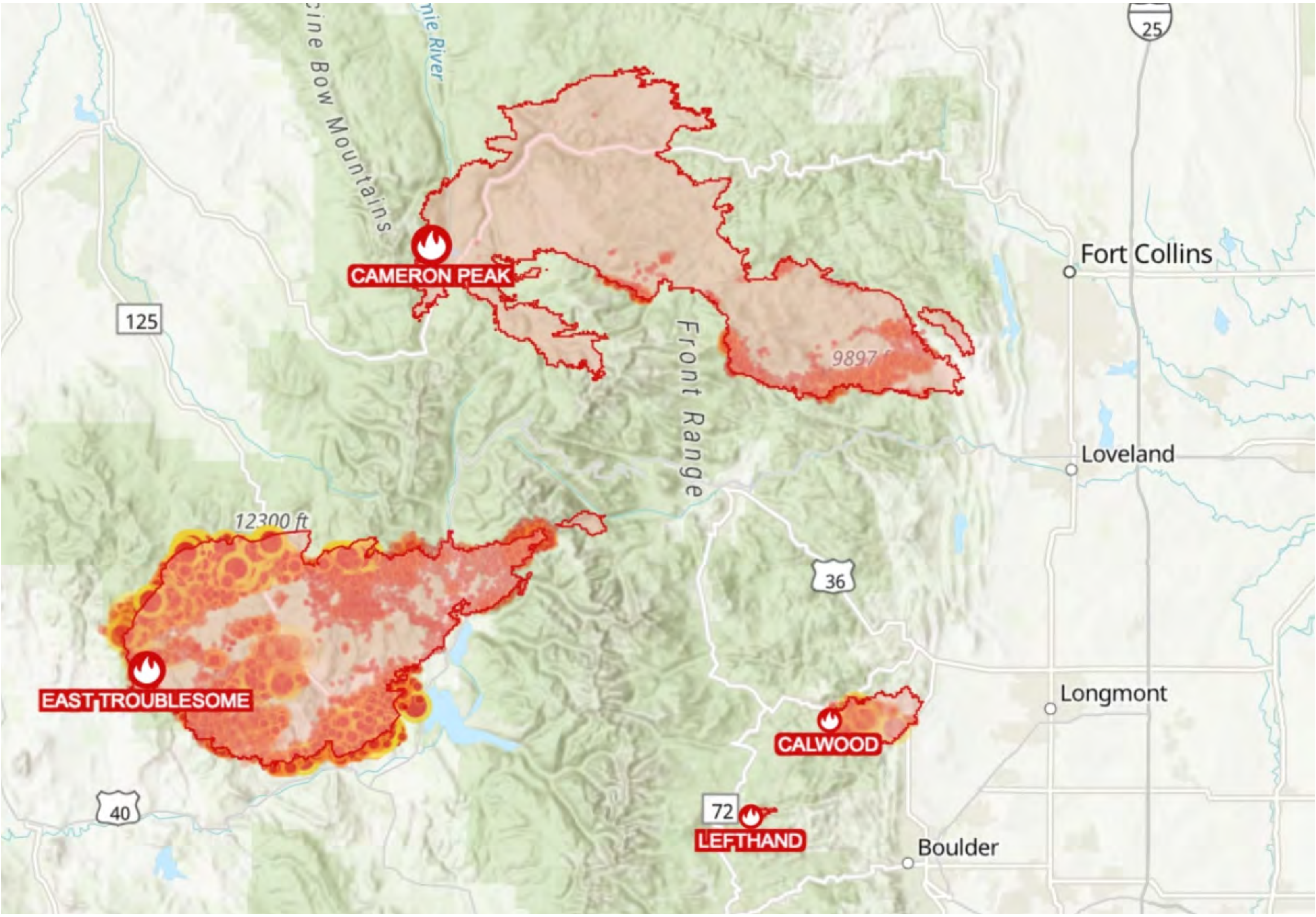


Figure 01.02.2 : 2020 Colorado Major Fire Map (ESRI/USGS)

Pine Gulch Fire account for the three largest wildfires in state history and burned over 625,000 acres (see Figure 01.02.2).

WATER QUALITY

Drought and warmer weather are increasing the severity of wildfires in mountain watersheds. Loss of tree cover leaves hillsides exposed which can cause flooding, erosion, landslides and sedimentation. Water quality is impaired as dirt and sediment is washed into reservoirs and rivers.

Hotter temperatures also mean hotter pavement temperatures. Tests have shown that pavements that are 100°F can elevate initial rainwater temperature from roughly 70°F to over 95°F. Increases in average water temperature can be devastating to all aspects of aquatic life. Reproductive rates and metabolism are heavily impacted by rapid water temperature spikes and fluctuations due to warmer stormwater runoff[7].

WATER SUPPLY

Water supply can be highly vulnerable to increased heat and wildfires. According to a Denver Water assessment, a 2-degree Fahrenheit average temperature increase would decrease water supply by 7 percent from the system's current yield, primarily due to an increase in evaporation. At the same time, water use would increase by 6% to keep crops and landscapes irrigated.

INVASIVE PESTS

Warmer, drier conditions make Colorado's beautiful forests and landscapes, such as those in Denver's Mountain Parks, more susceptible to pests and invasive species. Temperature controls the life cycle and mortality rates of pests and with warmer winter temperatures pests could persist year-round while new non-native pests are introduced. Drought also reduces trees ability to protect themselves from pest

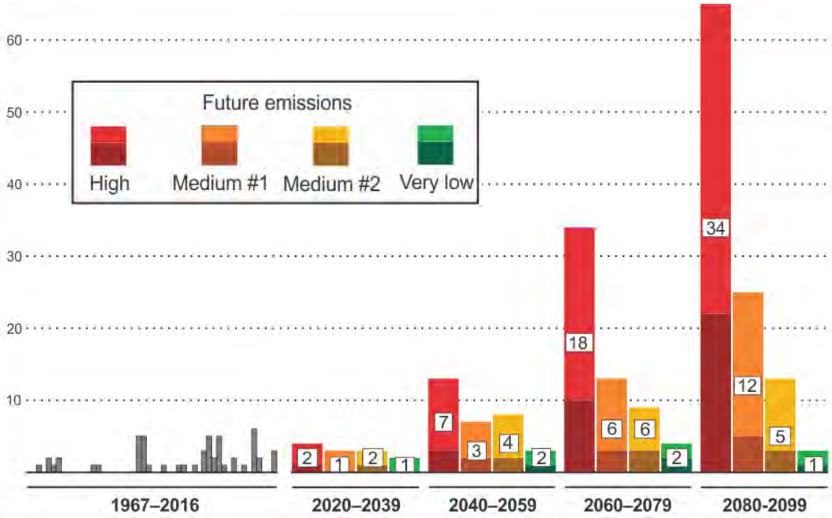


Figure 01.02.3 : 95+ degree days in Denver Metro Area https://www.rockymountainclimate.org/extremes/denver.htm

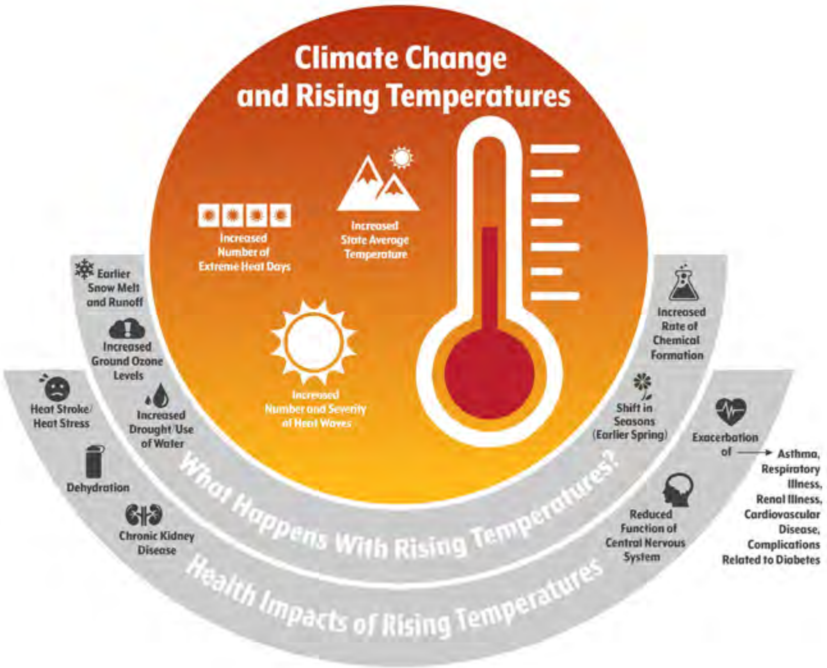


Figure 01.02.4 : Rising Temperature Impacts - Colorado Health Institute

outbreaks as shown by the ongoing mountain pine beetle infestation affecting 80% of the ponderosa-logepole pine forest and spruce beetle impacting 40% of the Englemann spruce forest[8].

TEMPERATURE

Median projections from twenty Colorado climate models indicate that with continued increases in heat trapping emissions a typical year would see seven or more days above 100 degrees. This makes Colorado one of the fastest warming states in the country[9]. Climate Central projects that heat wave days will jump from roughly ten a year to 50 a year by 2050[10]. By late century the projections indicate that a typical year could have more than one month's worth of 100-degree days[11]. This means that the hottest summers of the past become the average summer in the future.

Local impacts from rising temperatures will take a toll on Colorado's environment throughout the state and at the local level. It impossible to separate the impacts regionally from the impacts in individual urban areas as an increase in mountain wildfires from heat and drought negatively impacts drinking water supplies and regional air quality.

02.2 - COMMUNITY HUMAN HEALTH IMPACTS

COMMUNITY VULNERABILITY

Denver's Department of Public Health and Environment created a map of Denver's neighborhoods that illustrates the heat vulnerability for census tracts across Denver. In Figure 01.02.5, the darker red corresponds with the highest overall vulnerability. Two indicators of the built environment that have been associated with increased vulnerability to extreme heat include impervious cover and tree canopy.

Increases in impervious cover along with removal of vegetation leads to higher urban temperatures as the cooling properties of vegetation is replaced with impervious surfaces that trap and store heat. Impervious cover gain and tree loss will continue to exacerbate Denver's urban heat island (UHI). Certain groups of people are more vulnerable to heat related illnesses including children, older adults, people with pre-existing health conditions, outdoor workers, and the poor. Heat stroke,

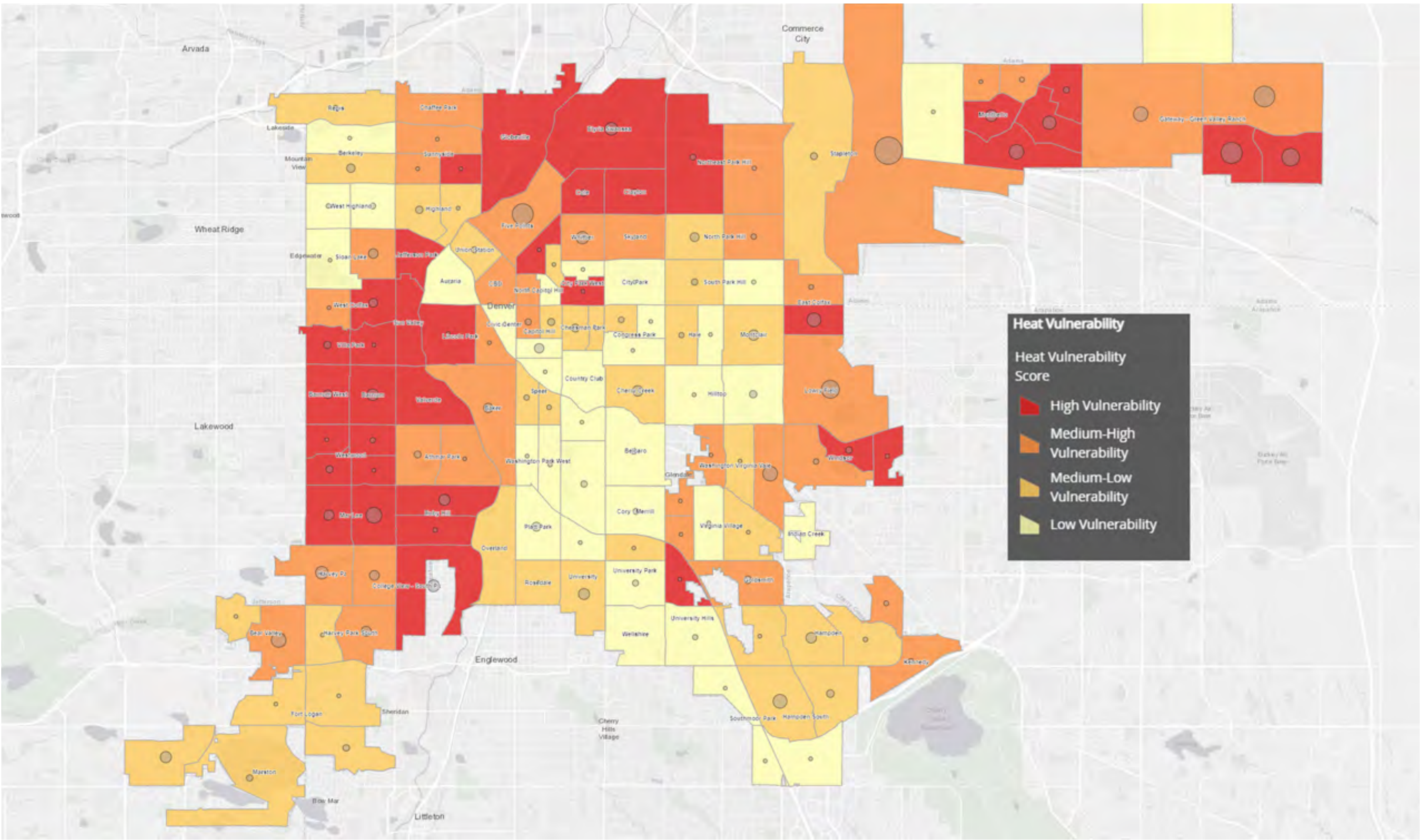


Figure 01.02.5 : DDPHE Heat Vulnerability Map for Denver

exhaustion, syncope, cramps, and rashes are all heat related illnesses. These community factors were also included in the DDPHE vulnerability mapping exercise.

AIR QUALITY

Rising temperatures increases the formation of ground-level ozone, a key component of smog. Ground level ozone is at its highest level when temperatures reach upper 80's to mid-90's[12]. Ozone can trigger a variety of negative health problems including chest pain, reduced lung function, emphysema, asthma, pneumonia, and cardiovascular disease.

Colorado is one of 10 states that have a year-round 'ozone season' which increases risks to vulnerable populations[13]. The population of Colorado residents aged 65 and older is expected to increase by 125% by 2030 putting even more people in the state at risk[14].

02.3 - INFRASTRUCTURE IMPACTS - ROADS AND BUILDINGS

Roads and bridges are critical infrastructure for more than just connecting towns and cities for transportation; they also provide critical access for first responders and aid during disasters. New infrastructure planning often uses historical data for design rather than looking at newer approaches that ensure infrastructure is more resilient to changing environmental conditions. New York City completed the *Climate Resiliency Design Guidelines* in March of 2019 to provide step by-step instructions on how to supplement historic climate data with specific, regional, forward-looking climate change data in the design of city facilities. Cities across the world, including Denver, could develop similar guidance and apply resilient design strategies when building or renovating roads, bridges, buildings, and any other capital infrastructure investments.

ROADS

The transportation system is both a large contributor to climate change as well as exceptionally vulnerable to the impacts of climate change. After energy production, transportation is the largest source of carbon emissions[15]. Transportation facilities like roads, tunnels, and bridges were often built near waterways and are vulnerable to extreme storm events that often shut down when most needed for critical transport and supplies during emergencies. Extreme heat can cause roads to buckle and the typical freeze/thaw cycle in Colorado can crack pavement and form potholes that will require increased maintenance or replacement dollars.

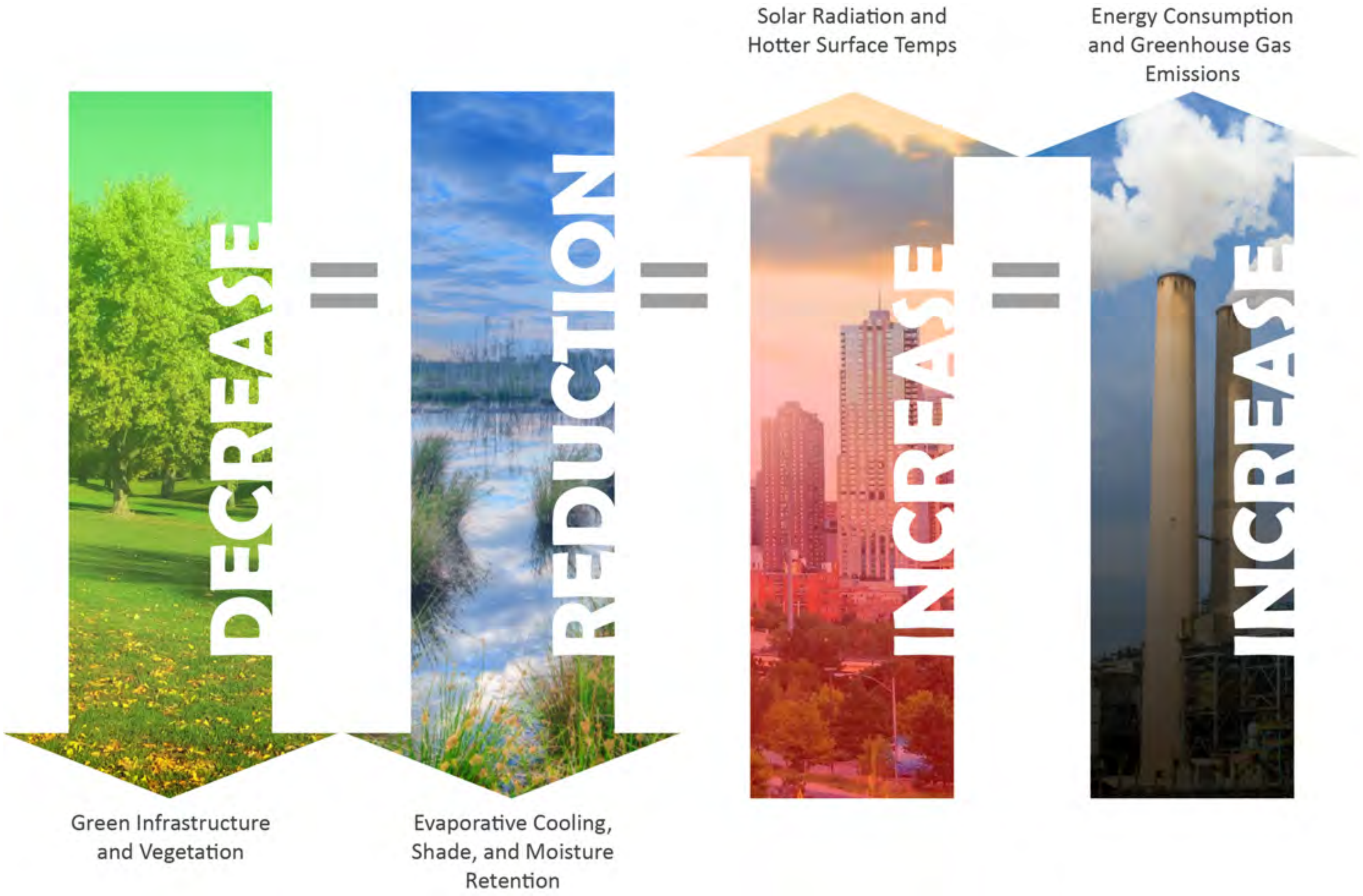


Figure 01.02.6 : Climate/Energy Feedback Loop

ENERGY GRID

Elevated temperatures from climate change and urban heat islands increase energy demand for cooling. According to the EPA, electricity demand for cooling increases 1.5–2.0% for every 1°F (0.6°C) increase in air temperatures, starting from 68 to 77°F. This would increase community-wide demand for electricity 5-10% to compensate for the heat island effect[16]. In times of extreme heat, the demand for cooling can overload electrical systems. The increase in electrical energy need is met by the burning of fossil fuel in power plants. This creates a negative feedback loop.

03 - GREEN INFRASTRUCTURE AS A NATURAL CLIMATE SOLUTION

Addressing climate change and its impacts will require immediate and bold actions from communities worldwide. Strategies thus far in Denver have focused on buildings, energy generation and the transportation sectors to reduce greenhouse gas emissions. But new science shows that fossil fuel reduction alone is not enough to address climate change. Every possible solution needs to be explored and employed including a set of solutions referred to as natural climate solutions.

This document has been written to help expand the understanding and use of green infrastructure as a natural climate solution and as a tool to mitigate and adapt to the current and rapidly changing climate. In part, because green infrastructure can be quicker and easier to implement than strategies to decarbonize the grid or create next generation mobility options. Green infrastructure can be implemented today in neighborhoods most vulnerable to extreme storm events and extreme heat.

03.1 - ENVIRONMENTAL HEALTH BENEFITS OF GREEN INFRASTRUCTURE

The scale of green infrastructure projects ranges from simple site-scale stormwater control measures (SCMs) to large complex regional-scale systems. Examples of typical site-scale practices are trees planted with adequate soil volume for optimal tree health, installing rain gardens or streetside stormwater planters along roads and streets, converting tree lawns to vegetated swales, and installing green roofs to reduce runoff from building rooftops. Green infrastructure can also refer to larger natural areas including parks, open spaces, forests, and floodplains. Regardless of the scale, green infrastructure solutions are available now and provide a host of environmental, social and economic benefits.

IMPROVE WATER QUALITY

Green infrastructure practices uses roots, soils, vegetation, and natural processes to treat and slow stormwater runoff. By slowing water down and holding it for short periods of time, green infrastructure facilities allow sediment to settle out while soils and vegetation remove and uptake pollutants including nutrients, metals and bacteria.

Figure 01.03.1 : 2010 Westerly Creek Flood

Figure 01.03.2 : 2010 Westerly Creek Flood, 1 day after

MANAGE EXTREME EVENTS AND PEAK FLOWS

The thoughtful integration of green infrastructure and gray infrastructure can extend the life-cycle of the stormwater system by helping to manage peak flows, which can free capacity from storm pipes and help delay the impact of surface flows from streets and reduce localized street flooding. Large, regional green infrastructure systems, like the redesign of Westerly Creek in Stapleton or City Park Golf Course (see figures 01.03.1 and 01.03.2, respectively), are designed to provide critical flood protection during major storm events.

Native and drought tolerant vegetation should be prioritized in all green infrastructure applications to withstand unpredictable rainfall patterns including periods of inundation followed by extended periods of drought. Careful thought and consideration have been given to the plant recommendations in this guide and the *Ultra-Urban Green Infrastructure Guidelines*. All plant lists should be considered breathing documents that will need to be adjusted and updated as climatic conditions continue to change.

REDUCE URBAN HEAT

Cities are covered in impervious surfaces which trap and radiate heat. Green infrastructure can mitigate urban heat islands from impervious surfaces along with the warming effects of climate change. Trees and other vegetation provide evaporative cooling benefits via evapotranspiration and shade. Evapotranspiration works using heat from air to evaporate water while tree canopy can block 70%-90% of the sun's rays from reaching the area below. Combined evapotranspiration and shade can lower summer temperatures by 2-9 degrees Fahrenheit[17].

INCREASE BIODIVERSITY AND HABITAT

By designating more space for native plant species, green infrastructure can provide essential elements that create a successful wildlife habitat, such as necessary food, cover, and water. Wildlife in this context refers to the fauna, birds, butterflies, bees and other pollinators that would naturally occur in the Denver region. Green infrastructure can also restore linkages between larger habitat areas, such as parks, open spaces, rivers and wetlands, leading to connections between populations of plants and animals that produce healthier wildlife communities in the urban setting[18].

BOOST OVERALL RESILIENCY TO CLIMATE CHANGE

As the climate continues to change, green infrastructure is a powerful tool for improving Denver's resiliency to the current and anticipated impacts. As discussed throughout this section, green infrastructure facilities can be designed and constructed to endure the projected precipitation variability which includes wet years followed by periods of drought. Green infrastructure reduces peak flows and flooding associated with extreme storm events. Green infrastructure can also be implemented to cool our city and provide a more comfortable environment during extreme heat events.

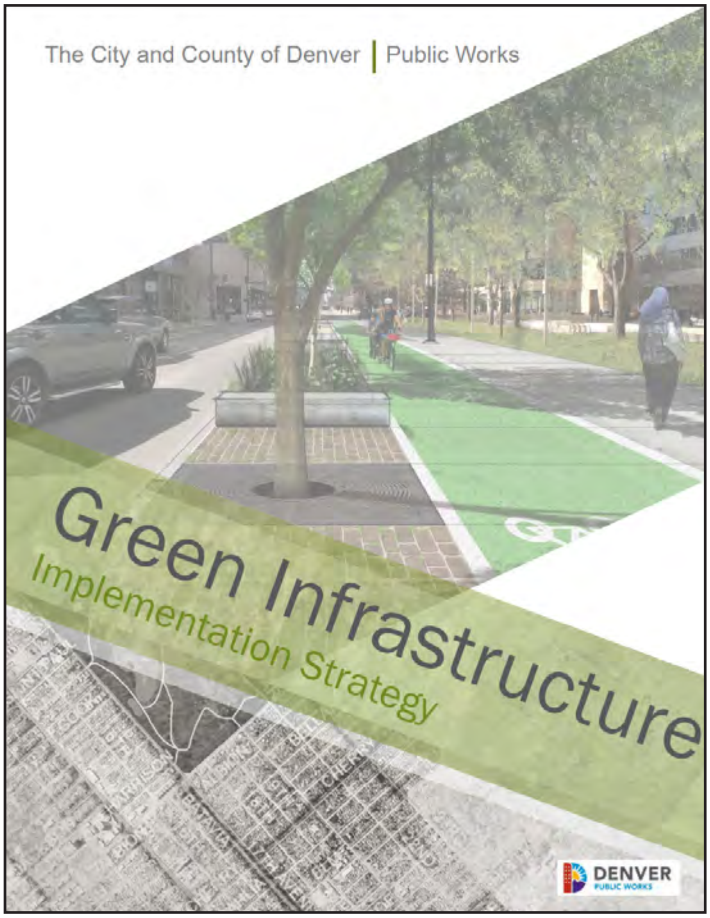


Figure 1.03.3 : Denver's Green Infrastructure Implementation Strategy

03.2 - COMMUNITY HEALTH BENEFITS OF GREEN INFRASTRUCTURE

MENTAL AND PHYSICAL WELL-BEING

Green infrastructure is an element of the built environment proven to have many positive health outcomes. In addition to the environmental benefits detailed in this chapter, access to quality green spaces including trees, parks, greenways, urban streetscaping, and gardens improve mental wellbeing for all ages. Access to green spaces can reduce stress, increase social cohesion, result in shorter hospital stays and fewer health complaints, and improves student learning and attentiveness[19].

MULTI-MODAL BENEFITS

Complete Streets must also be green streets. Installing green infrastructure can make streets safer by calming and slowing traffic thus making it safer for pedestrians to cross the street. Green infrastructure can also create safer streets by intercepting stormwater and reducing localized flooding at intersections, ramps or sidewalks that can make crossing streets dangerous during storm events. By shading streets, tree canopy makes the biking and walking environment more pleasant by reducing temperatures, attenuating noise, and improving air quality as well as extending the life of pavement.

AIR QUALITY BENEFITS

Through uptake and deposition, vegetation directly removes air pollutants like nitrogen dioxide and particulate matter that can be detrimental to public health. Green infrastructure also reduces ground level ozone through both pollutant removal and by providing a cooling effect that results in fewer emissions associated with air conditioning. Vegetation with the largest leaf surface areas and high transpiration rates are the most effective at trapping pollutants.

03.3 - ECONOMIC HEALTH BENEFITS OF GREEN INFRASTRUCTURE

Many varied economic benefits can be tied to green infrastructure including increased property values, higher rental and retail sales, reduced energy demands and costs, reduced crime rates, and an increased life span of road infrastructure. One of the greatest new economic opportunities is creating a green economy and workforce In Denver.

NEW GREEN JOBS

With the investment of new site-scale and large-scale green infrastructure throughout Denver, an opportunity exists to develop a workforce to design, install and maintain green infrastructure. The Office of Green Infrastructure (OGI) will identify programs and initiatives to provide employment opportunities for those in economically disadvantage areas and backgrounds. OGI's efforts will be coordinated with a larger green jobs strategy being developed by the Denver Office of Climate Action, Sustainability & Resiliancy (CASR) and the Denver Office of Economic Development (OED).

Like the Denver Construction Careers Pilot, a green jobs program has the possibility of helping people who face barriers to employment such as veterans, formerly incarcerated individuals, Colorado Works (TANF) program participants, those exiting the foster care system, and people

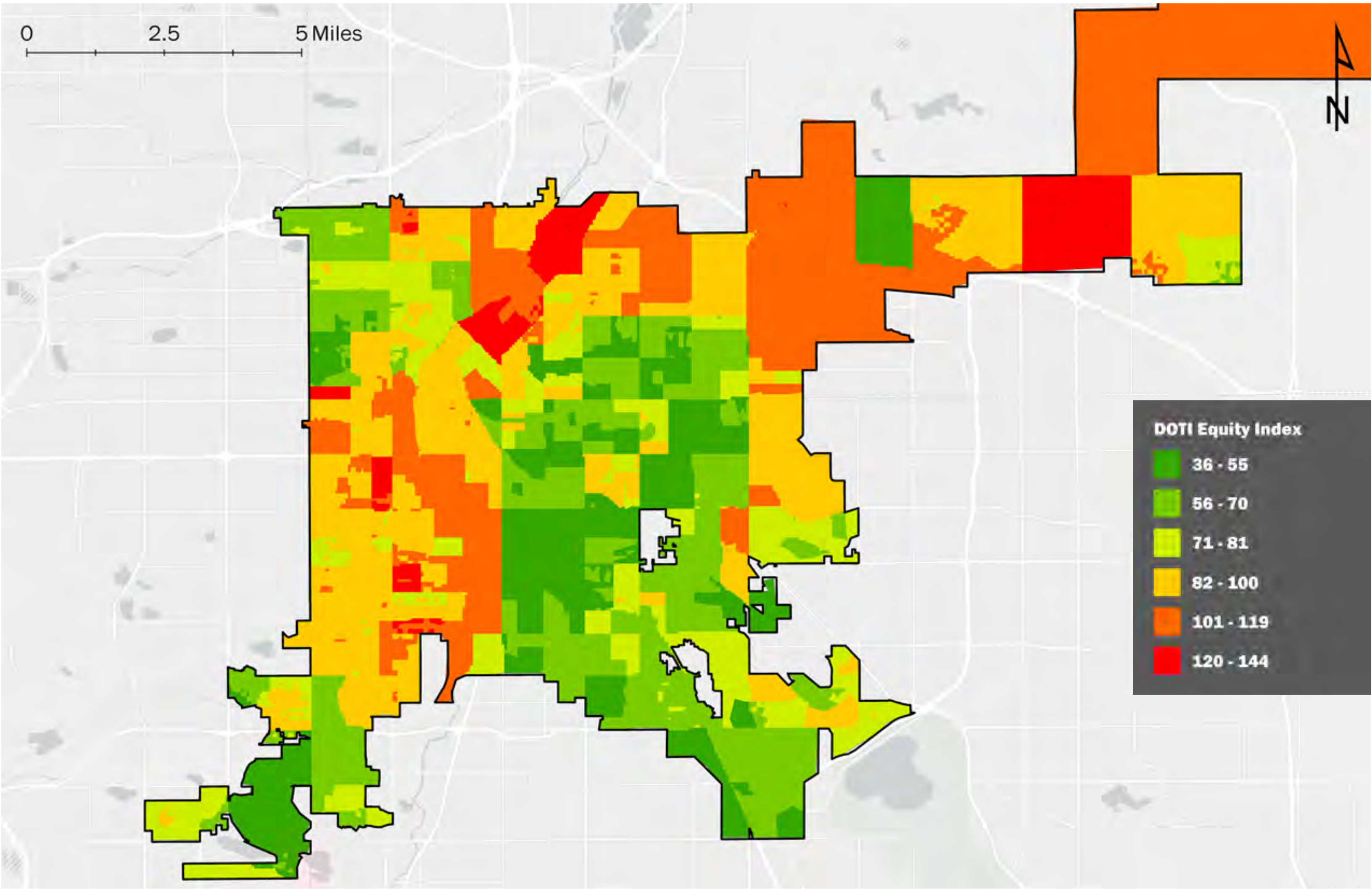


Figure 01.03.4 : Department of Transportation and Infrastructure's (DOTI) Equity Index. Higher numbers and warmer colors indicated areas in greater need of infrastructure investment. (March 2021)

who have experienced homelessness. Any green jobs strategy should also include an apprenticeship program to ensure that workers can grow in their careers and advance beyond entry-level positions.

03.4 - EQUITABLE IMPLEMENTATION OF GREEN INFRASTRUCTURE

Equity is achieved when everyone, regardless of who they are or where they come from, can thrive and prosper. Where there is equity, a person's identity does not determine their outcome. Equitable capital investments must create access to high quality of life infrastructure, such as green infrastructure, for everyone. Often times, the distribution of tree canopy is lower in areas where residents are underserved and more vulnerable to extreme heat. Denver's Department of Transportation and Infrastructure (DOTI) has created an Equity Index Map (See Figure 01.03.4) to identify parts of the city where the City needs to do more to ensure residents have equal access to opportunity and where DOTI should direct resources and investment to combat historical inequities and improve the overall quality of life for all residents.

DOTI's Equity Index includes eleven sub-models. Where possible, sub-models were developed using 2019 American Community Survey and census tract data. The sub-models are percentage of minority populations, population in poverty, unemployment, education of less than a high school equivalency, traffic safety, key destinations and children, populations over 70 years of age, households with no vehicles, female heads of households, population with disabilities, health, and language challenged populations.

The final DOTI Equity model weights the sub-models to generate a final raster dataset. Weighting considers the importance of the input data sets in determining equity across the city. For instance, a sub-model where populations would be more impacted by a DOTI project weighted higher than those that could be less impacted. The sub-models were weighted as follows:

WEIGHT 3

- Percent of Minority Populations
- Population in Poverty
- Unemployment

WEIGHT 2

- Education of Less than High School Equivalency
- Traffic Safety
- Key Destinations and Children
- Populations of Age 70+
- Households with No Vehicle
- Female Heads of Household
- Population with Disabilities

WEIGHT 1

- Health
- Language Challenged Populations

04 - USING THE CONTINUUM

The Green Continuum: Streets contains information for project planners, designers, and managers who are implementing green infrastructure along with transportation or other physical infrastructure improvements. The document is meant to provide context, guidance, and inspiration for implementing a variety of green infrastructure strategies designed to reduce stormwater water runoff, improve water quality and/or mitigate urban heat along streets in Denver. This document expands the toolbox for SCMs. Chapter 2 describes the principles of SCM design to meet stormwater and heat objectives.

Chapter 3 provides context by introducing and defining Five Levels of Green (LoG) – which are groups of SCMs distinguished by performance when reducing runoff or temperature. It also contains performance and design criteria summaries for each LoG. While a certain LoG may be better performing for one objective, Levels of Green can be combined on a project to provide multiple outcomes and benefits.

Chapter 4 is designed to inspire by showing examples of SCMs. The examples are paired with narrative text explaining why that SCM is appropriate in context and how it’s components can be designed to fit into a specific LoG. Components are pieces that, when assembled, form an entire SCM. Chapter 4 also provides options for key components and guidance for selecting from those options. Chapter 4 intentionally shows SCM examples as well as component options to encourage designers to be creative.

Chapter 5 offers guidance for project managers to understand the heat and stormwater needs of the project, which can be used to identify the appropriate Level or Levels of Green. It lists the considerations important for green infrastructure projects specifically during the planning and design process.

Finally, the Appendices contain plant lists for the SCMs and a summary of the technical analysis performed to establish the performance and design criteria for each Level of Green.

ENDNOTES

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Chapter TWO

DESIGN PRINCIPLES

01 - STORMWATER

Managing stormwater runoff has, to date, been the primary driving principle behind the increased use of green infrastructure in urban environments. Green infrastructure has become widely recognized as a more sustainable method to capture and treat stormwater runoff versus relying solely on underground gray infrastructure systems alone. As discussed in the previous section, green infrastructure has a host of co-benefits, but stormwater management remains one of the primary design principles behind the introduction of the Levels of Green in the following chapter.

Sustainable stormwater principles aim to improve the quality of stormwater runoff while also reducing the quantity of runoff and peak flow rate. Traditionally, this has been determined by designing best management practices to meet a water quality capture volume (WQCV) reduction standard. In 1989, the target of 0.6 inches was developed by Urban Drainage and Flood Control District (now the Mile High Flood District) as this number corresponded to the 80th percentile runoff-producing storm event, which is a common regulatory target for reducing pollutant concentrations in stormwater runoff.

As Denver continues to grow in impervious cover, it is increasingly difficult to consistently find the space for stormwater control measures (SCM) designed to capture and treat the full water quality capture volume and often leads to an all or nothing approach. This document defines other stormwater management practices that reduce runoff and improve water quality. These practices, while not storing the full WQCV, still improve water quality because pollutant load reductions are proportional to reductions in runoff volume. Modeling of a synthetic streetscape demonstrated that annual runoff reductions generally plateau as a greater percentage of the WQCV is stored (See Appendix 3). This means that the greatest increases in runoff reduction occur when some stormwater control is added to sites with little or no existing control. This underscores the value of providing lower levels of stormwater control to more areas rather than providing full regulatory control in smaller areas.

01.1 - STORMWATER DESIGN PRINCIPLES

REDUCE IMPERVIOUS COVER

In the fall of 2018, a team at the University of Colorado Boulder completed an Impervious Cover Forecasting Model for the Denver's Office of Green Infrastructure (OGI). The purpose of the forecasting model was to determine the anticipated amount of impervious cover gain by 2040. Impervious cover was chosen as a parameter as it is an important watershed health indicator and contributes to higher stormwater runoff, greater sediment yields, increased pollutant loads, higher stream temperatures, channel erosion, and decreases in aquatic species richness. The Model forecasted that impervious cover in Denver would grow from 49% in 2017 up to 61-67% impervious cover by 2040. Impervious cover not only has tremendous impacts to receiving watersheds but also contributes to urban heat islands.

Reducing impervious cover is a simple concept yet seems difficult to achieve in today's development where land values are at a premium. Any reduction in impervious cover results in downstream benefits. This basic approach must be considered early in the planning and design stages of any project. The first step is to utilize good site design practices that minimize soil disturbance and protect on-site natural features including mature vegetation and natural drainage features. Minimizing driveway and house footprints, narrowing road sections, and limiting parking lot size also reduce parcel-level impervious cover.

The City and County of Denver can also reduce impervious cover citywide by de-paving or retrofitting unused portions of the right-of-way or vacant parcels and parking lots with green infrastructure. A recent example of this approach was a project completed in 2019 at 21st & Broadway (See Figure 2.1) by DOTI's Transportation and Mobility Group and the OGI.

MINIMIZE DIRECTLY CONNECTED IMPERVIOUS AREA

Stormwater runoff from pavements and rooftops should ideally be directed to vegetated landscapes when possible. The goal of minimizing directly connected impervious area (MDCIA) is to route runoff from impervious areas through vegetated areas capable of intercepting stormwater where it can be filtered or infiltrated. Vegetated areas receiving runoff can include grass buffers, bioswales, rain gardens, or permeable pavements.

Integrating MDCIA design practices can improve the quality of

Figure 02.01.1 : 21st & Broadway Stormwater Project

Figure 02.01.2 : Flow-through and shallow-storage landscapes, Bell Street in Seattle, WA. - See Appendix, Section 02 for attribution.

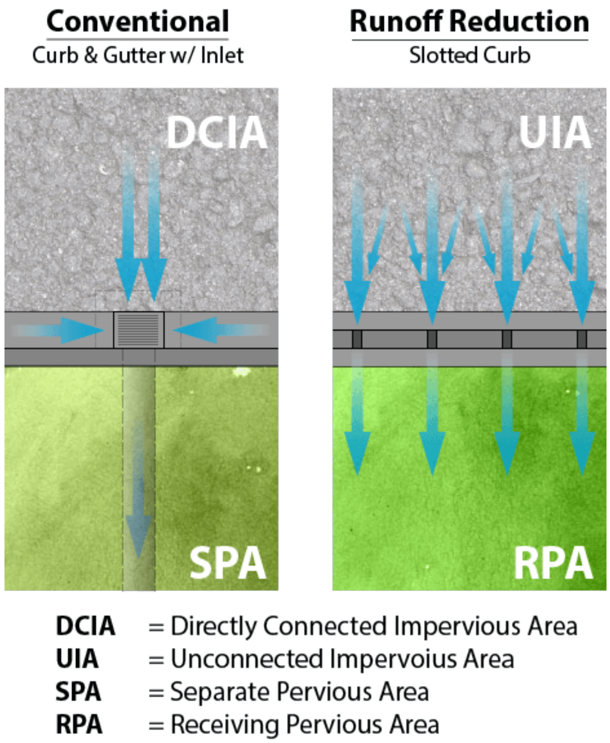


Figure 02.01.3 : Comparison of conventional versus runoff reducing approach.

stormwater runoff, reduce the volume of runoff and reduce peak flows. Even the most limited integration of MDCIA reduces the amount of stormwater runoff and helps restore pre-development hydrology. MDCIA is a low-cost runoff reduction practice that can make use of existing or planned green space and can often reduce or eliminate the size or need for volumetric SCMs designed to store regulatory water quality capture volumes.

GREEN INFRASTRUCTURE STRUCTURAL CONTROLS

After minimizing runoff by reducing impervious cover and employing MDCIA practices, structural stormwater control measures (SCMs) can be implemented to treat any remaining stormwater runoff. Green infrastructure structural controls are engineered systems designed to provide additional water quality and volume reduction benefits and are often selected to meet a certain water quality capture volume.

The City and County of Denver generally follows Mile High Flood District (MHFD) guidance when it comes to the selection and design of structural control measures. In 2016, the City and County of Denver in partnership with MHFD went a step further and released the *Ultra-Urban Green Infrastructure Guidelines* (UUGIG) which included technical guidance for smaller, engineered structural controls which could be used in highly urban, space constrained settings. Several new stormwater control measures were detailed in the UUGIG which included streetside stormwater planters, curb-extensions, green gutters, green alleys, and tree trenches. These practices treat stormwater and associated pollutants as close as possible to the source. Larger, sub/regional green infrastructure controls can also provide flood control and water quality for drainage areas between 130 acres up to one square mile as recommended in the MHFD *Criteria Manual, Volume 3*. These controls are usually not feasible within the street right-of-way and therefore are not detailed in this guide. Whether small or large-scale, engineered structural controls are meant to work in tandem with planning and design-based approaches to minimize overall impacts of urbanization.

02 - URBAN HEAT & TREE CANOPY

As discussed in Section 1, one of the biggest threats from climate change in Denver is the constant rise in average temperature year after year. In addition to rising temperatures from greenhouse gas emissions, the increase in impervious cover and the removal of trees and vegetation also contributes to increased heat in the urban core.

Because of the detrimental impacts from heat to other environmental systems and to social and human well-being, mitigating heat is also now a primary driving principle behind the implementation of green infrastructure in Denver, especially along city streets. Shading pavements and streets prevents heat storage and later release which decreases temperatures associated with urban heat islands while providing refuge for street users. As detailed more in Chapter 3, modeling efforts by the Office of Green Infrastructure has shown an approximate 2°F decrease in land surface temperatures for every 10% increase in canopy coverage.

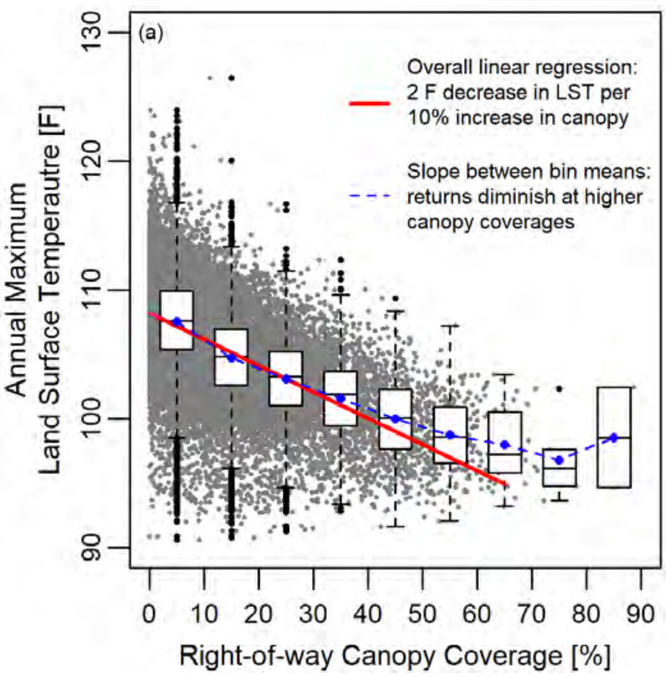


Figure 02.02.1 : Annual Maximum Land Surface Temperatures

Figure 02.02.1 illustrates that increasing canopy coverage on streets with the lowest canopy cover (0-10%) are likely to see the greatest reductions in land surface temperatures.

02.1 - TREE CANOPY DESIGN PRINCIPLES

TREE PRESERVATION

It should be no surprise that larger trees provide more services to the city than their smaller counterparts. Existing mature trees have far greater benefit to the urban environment than smaller new trees. As the tree grows larger the scale of the benefits grow along with it. Protecting existing trees and improving the growing conditions should be prioritized in the City of Denver. Currently, the City and County of Denver does not have a Tree Ordinance codifying tree preservation, however public trees and some setback trees are protected under Chapter 57 (unlawful to damage/ remove public trees and may result in compensation for value loss). In addition, the Office of the City Forester (OCF) has tree protection requirements and mitigation measures that represent best management practices. Cultivating better growing conditions can include improving soil volumes (see Figure 02.02.2), eliminating sources of compaction, air spading compacted soils, and watering throughout the year (establishment, winter, supplemental, etc).

SOIL VOLUME

All vegetation requires nutrients, oxygen and water to thrive which are derived from soil and transported by the roots to the rest of the tree. Trees in urban environments are placed in harsh growing conditions with limited soil volumes, poor nutrient levels and compacted soils. This has resulted in the average life span of urban trees being roughly seven years in Denver. Greater soil volumes and available rooting space can increase the life span of Denver's urban forest. While several factors are responsible for how long a tree will live and how large a tree will get, research shows[1] a direct correlation between the size of the tree and greater soil volume in combination with nutrients supportive of sustained plant growth. Based on this research, the Office of the City Forester (OCF) recommends 1,000 cubic feet of soil per tree when available.

Throughout the City, there are many areas where existing conditions limit the amount of available space in the amenity

Estimated crown spread = 10 feet diamter

120 Cubic Feet

Estimated crown spread = 21 feet diamter

500 Cubic Feet

Estimated crown spread = 30 feet diamter

1000 Cubic Feet

Figure 02.02.2 : Soil Volumes for Trees - Image Source; DOTI Office of Green Infrastructure - Informational Source; Casey Trees, Washington DC - Tree Space Design

zone where trees are typically planted. The construction of sidewalks and high foot traffic over tree lawns can compact the soil which limits root expansion and both air and water uptake. Several design methods are available to increase soil volumes in urban areas with constrained growing conditions. Installing structural cells, root paths, structural soils (in combination with other methods) or suspended pavements can help support larger soil volumes and allow for rooting below adjacent pavement.

In urban areas this can require removal of the hardscape, remediation of the soil, and the replacement of the hardscape. Retrofits in certain locations may allow opportunities for hardscapes to be replaced with open soil areas or permeable pavers. Tree roots can grow in the soil-filled void spaces with better access to air and water which promotes a healthier, longer-lived street tree. The structural cells and other mentioned techniques can be used on both new and existing trees, although existing trees will require additional considerations.

TREE SELECTION AND SPECIES DIVERSITY

The Office of the City Forester (OCF) is responsible for issuing and updating Denver's approved street tree list. The current street tree lists can be found on the Office of the City Forester's website. In addition to the official OCF Street Tree list, both this document and the *Ultra Urban Green Infrastructure Guidelines* include additional guidance on tree and plant selection including abbreviated lists best suited for stormwater facilities based on research and monitoring data. The OCF has final approval and is responsible for permitting trees within the rights-of-way. When possible, trees should be locally grown or sourced from locales with similar growing conditions. The OCF also provides guidance on species diversity that should be followed on all projects. Projects that use any Levels of Green are required to follow these guidelines to ensure a healthy citywide tree canopy.

OPTIMAL TREE PLACEMENT

Tree locations and species should be chosen with consideration to existing species, above and below ground conditions including utilities, available soil volume, surrounding hardscape or adjacent structures, environmental conditions specific to that location, sight triangles, area use, pedestrian access, and other locally appropriate site constraints that may impact tree health. Mature tree size above and below ground should fit the space provided. Even with the best intentions, too often the wrong tree is planted leading to continual challenges, increased maintenance costs, and shortened tree lifespans.

Figure 02.02.3 : Ideal tree planting; Courtesy of Denver Office of the City Forester

Figure 02.02.4 : Stormwater Control Measure in Fort Collins

ENDNOTES

1 Casey Trees, Washington DC. *Tree Space Design: Growing the Tree Out of the Box.* 2008. https://caseytrees.org/resources-list/tree-space-design-growing-tree-box/

Chapter THREE

LEVELS OF GREEN

01 - LEVELS OF GREEN

This chapter contains five sections that detail five different levels of green infrastructure that are appropriate for city streets. These are referred to as Levels of Green (LoG) 1 through 5. By diversifying and expanding the green infrastructure toolkit, a greater number of capital projects can install green infrastructure based on factors including environmental need, available space, land use, and budget.

Levels of Green 1-2 are less engineered than the other LoGs and designed to reduce impervious area by planting trees and vegetation with ideal growing and soil conditions. Trees are spaced according to soil requirements, surrounding conditions, adjacent land uses, and species diversity regulations. These levels are geared towards projects on streets with high urban heat and no regulatory stormwater requirements. LoG 3 designs begin to introduce stormwater runoff from the street into the facility, while LoG 4-5 are designed for projects that must meet regulatory water quality volumes or located in a high priority water quality basin[1].

The following pages include the defining characteristics, example applications, and performance metrics and criteria for each LoG to help designers determine the ideal approaches for any given project. Each section contains a header image showing a typical configuration for that LoG. It's important to note that these images are only examples, and that all projects have site-specific goals and objectives that are unique. Stormwater control measures (SCM) from all levels can be mixed and matched as site conditions can vary tremendously from block to block or even within a given block. Each of these levels can be applied at the scale of an individual control measure, in aggregate at an intersection, or at a block or multi-block scale.

Table 03.01.1 contains an at-a-glance summary of the defining characteristics, design guidelines, and performance metrics for each LoG. The defining characteristics are the hydrologic position of the SCM within the rights-of-way (ROW) and the storage volume of the SCM relative to its tributary area's water quality capture volume (WQCV%). The design guidelines detail vegetation typology and tree density as well as the constituents, depth, and texture class for the soil media. The vegetation and media design guidelines for each LoG shown in Figure 03.01.1 are just that – guidelines. The figure contains a summary of the anticipated performance, assuming control measures from a single LoG were included throughout a project. Performance metrics shown include peak flow reduction of a water quality design storm and average reduction of mean radiant temperature on the hottest day of the year (See Chapter 3, Section 2, and Appendix 3 for more detail). The performance criteria are guidelines to assist designers in setting water quality and runoff reduction goals and applying control measures to help meet those goals. Further considerations can be found in the components section of Chapter 4.

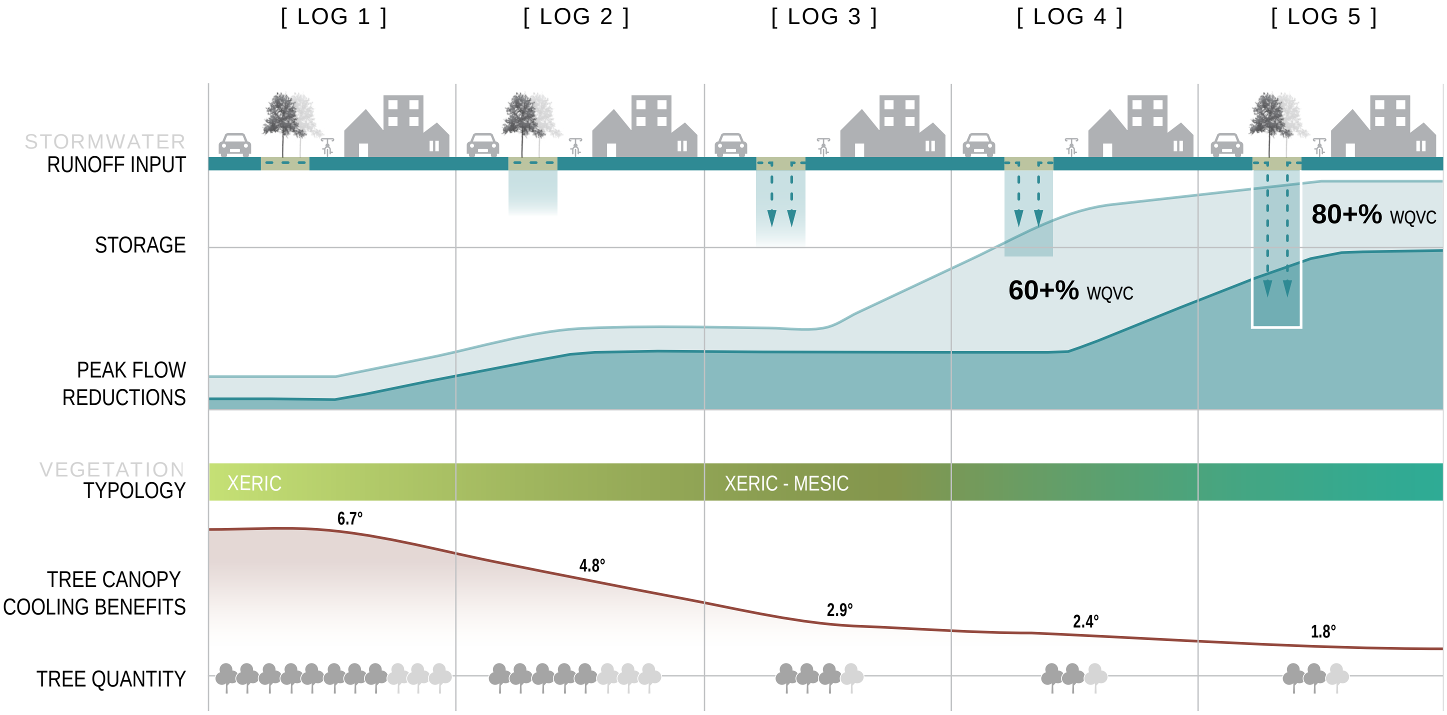


Figure 03.01.1: LoG Characteristics Diagram

[LEVEL OF GREEN 1]

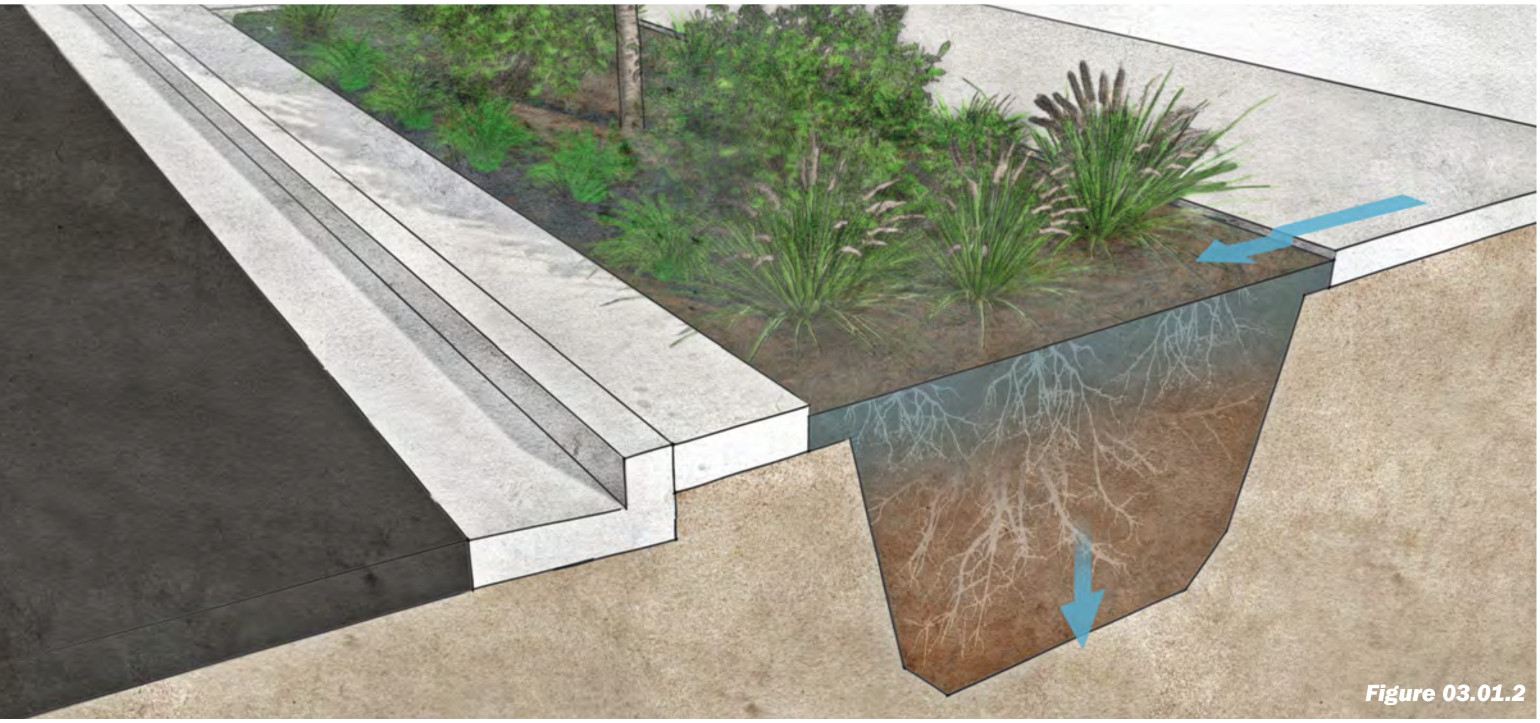


Figure 03.01.2

Figure 03.01.3: Example of LoG1 - Brighton Blvd.

01.1 - HIGH-PERFORMING LANDSCAPES (LOG1)

Level of Green 1 (LoG1) design focuses on the reduction of impervious surfaces by increasing landscaped areas and diversifying the tree canopy within the ROW. Proper attention should be given to providing adequate soil volumes so that trees and vegetation can reach maturity. LoG1 landscape areas should be at the same grade as the surrounding paving, but may be slightly lower to account for mulch, plantings, or other aesthetic reasons. There should be no raised curb or barrier separating the pervious area from the adjacent walkway/amenity zone, so that flow may incidentally enter the area and infiltrate in the soil below.

APPLICATION:

LoG1 designs are extremely versatile and could be implemented in a variety of contexts and ROW widths where improved growing conditions are desired for street trees and other vegetation. Because the landscaped area is at the same grade as the adjacent walkway, LoG1 can be implemented next to parking and along amenity zones where pedestrians frequently cross a right-of-way (ROW). In pedestrian areas, accommodations should consider vegetation resiliency to foot traffic. Tree grates or permeable pavers can be used to accommodate this in appropriate settings with Office of the City Forester (OCF) approval.

Common applications for LoG1 control measures include:

- Walkway areas around pedestrian malls, along streets in front of cafes and shops;
- Sidewalk repair and connection projects;
- Redevelopment projects in areas which need to reduce urban heat;
- Installation of bicycle facilities; and
- Landscape renovations in existing tree-lawns or medians where dead or dying trees are being removed/replaced without significant structural renovations.

DEFINING CHARACTERISTICS:

The following are characteristics of LoG1 and differentiate it from LoG2.

- **TRIBUTARY:** LoG1 control measures accept incidental runoff from walkway areas.
- **ENVIRONMENTAL:** LoG1 emphasizes mitigation of urban heat by increasing the vegetated area and tree canopy, water quality and flood risk are not primary goals of this control measure.
- **STREET USE:** LoG1 designs are most appropriate in ROWs with higher pedestrian flows, higher parking turnover and higher urban densities. LoG1 control measures are ideal for pedestrians to park next to and cross regularly, for example in between a shopping front and streetside parking. For these reasons LoG1 designs are most applicable in urban, commercial, and mixed-use areas.
- **VOLUME / DEPRESSION:** LoG1 SCMs typically do not have any depression or storage volume. Designs should allow for flows to run onto the landscape area for incidental infiltration.
- **DRAINAGE INFRASTRUCTURE:** LoG1 designs do not include underdrains, nor do they require connections to storm drain systems.
- **UTILITIES:** LoG1 requires minimal vertical clearance for the shallow soil amendments and the root systems of trees and vegetation. LoG1 is applicable in locations where there may be surface utilities surrounding the control measure or subsurface utilities under the control measure.
- **SOIL MEDIA AND PLANTING:** LoG1 should provide 750-1000 cubic feet of uncompacted soil rooting space dependent on tree species and size. Strategies such as open planting areas, structural cell systems and tree planting trenches with connector spans, root paths, break out zones, or other uncompacted soil volume techniques/technologies are utilized to maximize soil volume. Ideal growing conditions start with providing adequate soil volumes and space for trees to reach maturity. Tree species are then selected that fit within the above ground space constraints and considerations for long-term branching structure and canopy are factored into tree selection.

PERFORMANCE:

- 0.6”, 2-hr peak flow reduction for a project: 5-15%
- Annual runoff reduction for a project: 5-10%
- Annual runoff reduction for the tributary area: >75%
- Mitigation of average temperature on very hot days: 1.1-6.7°F

CRITERIA:

- Run-on ratio: 1:1 to 3:1
- Canopy coverage at maturity: 70-95% of ROW length, see Chapter 5, section 3 for more information
- Percent WQCV requirement: None
- Surface storage depth: 0” (Allowable grade differential <4” from walkway)
- Media or Soil: Native soils, amended or imported suitable for tree growth
- Recommended soil volume: 750-1000 ft^3 / large tree
- Length: 15’
- Width: 5’ (minimum) to limit of pedestrian route (maximum)
- Spacing: 1 tree every 25 linear feet (ornamental species) to 35 feet (shade species)

Figure 03.01.4: Example of LoG1 - S. Broadway Blvd.

[LEVEL OF GREEN 2]

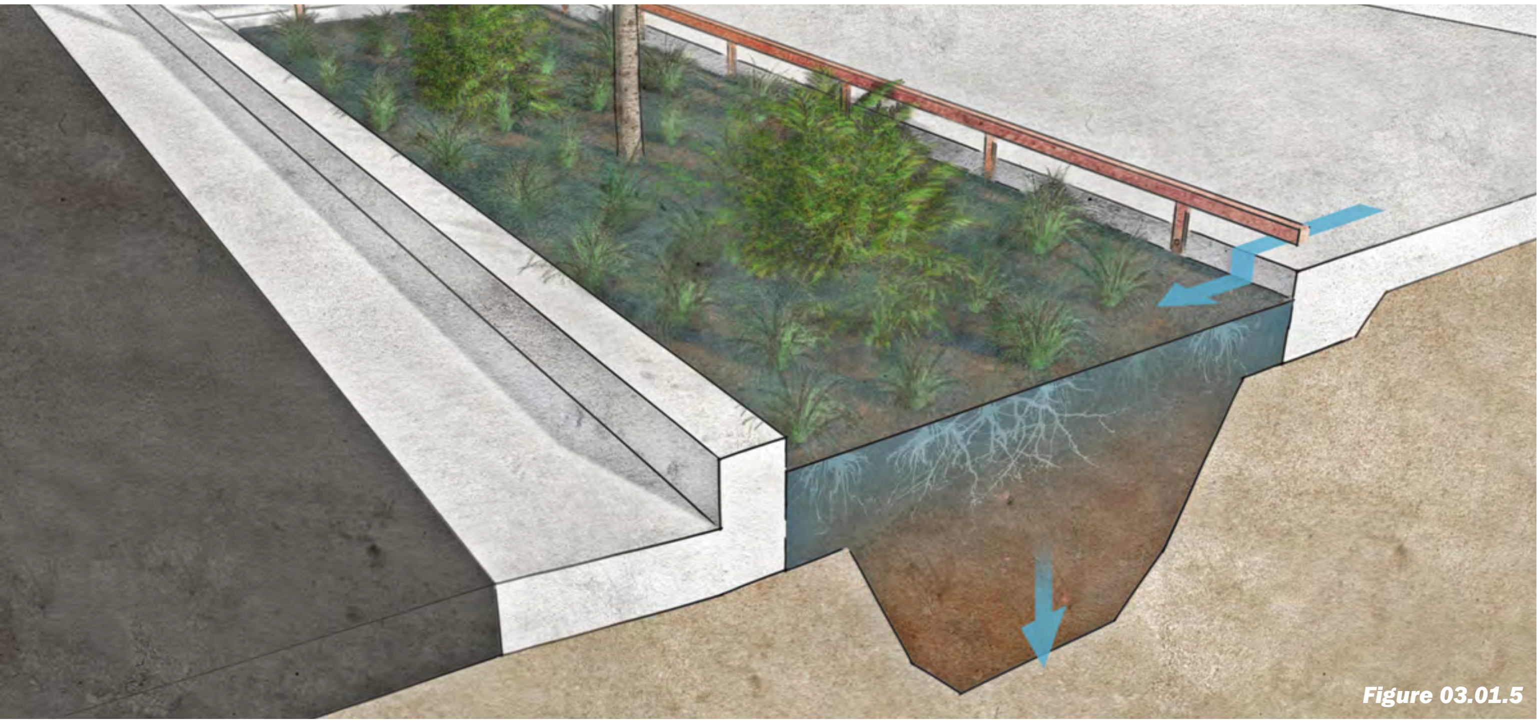


Figure 03.01.5

Figure 03.01.6: Example of LoG2 - Brighton Blvd.

01.2 - SHALLOW INFILTRATING LANDSCAPES (LOG2)

Level of Green 2 (LoG2) design intentionally directs runoff from impervious sidewalks, walkways, and amenity areas (not roadway) into slightly depressed adjacent pervious landscapes. LoG2 landscape areas are designed to be depressed 2”-4” to accept runoff and infiltrate small storm events. LoG2 is focused on mitigating urban heat while providing minor runoff reduction and water quality benefits.

APPLICATION:

LoG2 designs are ideal in a variety of contexts but most commonly in higher-density urban, multi-use, and commercial areas where ROW widths may be limited. Flows entering the stormwater control measure (SCM) will infiltrate until the soil is saturated and excess flows will then pond and over top the adjacent curb. Excess flows should be directed toward the gutter and street and away from any adjacent structures.

If the ROW width does not have space adequate for LoG3, then a LoG2 SCM can be used. LoG2 can be implemented next to parking and along amenity zones where pedestrians will be crossing the ROW frequently. Accommodations should consider vegetation resiliency, ADA compliance, and hazards associated with introducing a small depression near the walk zone.

Common applications for LoG2 SCMs include:

- Residential, commercial, or industrial area tree lawns;
- Sidewalk repair and connection projects;
- Redevelopment projects in areas with need to reduce urban heat effects; and
- Landscape renovations in existing tree-lawn where dead or dying trees are being removed / replaced, without significant structural renovations.

DEFINING CHARACTERISTICS:

The following are characteristics of LoG2 and differentiate it from LoG1 and LoG3.

- **TRIBUTARY**: LoG2 SCMs only accept runoff from walkway areas.
- **ENVIRONMENTAL**: LoG2 emphasizes mitigation of urban heat by increasing the vegetated area and tree canopy, with some benefit to water quality and flood risk. If water quality or flood risk are primary concerns of the location, consider LoG3 with sufficient ROW width or LoG4 if ROW width is limited.
- **STREET USE**: LoG2 designs are most appropriate in ROWs with moderate pedestrian flows and moderate parking turnover. LoG2 SCMs are feasible for pedestrians to park next to and cross occasionally, for example in a residential tree lawn.
- **VOLUME / DEPRESSION**: LoG2 SCMs include a slight depression from the adjacent walkway in order to contain and infiltrate flows.
- **DRAINAGE INFRASTRUCTURE:** LoG2 designs do not typically include underdrains or connections to storm drain systems.
- **UTILITIES**: LoG2 requires minimal vertical clearance from subsurface utilities for soil amendments and the root systems of vegetation. Where vertical clearance is a concern due to shallow utlities, LoG2 can also be planted with shrubs, grasses, and groundcovers to limit conflicts. LoG2 is most applicable in locations where there may be numerous surface or subsurface utilities surrounding the SCM.
- **SOIL MEDIA AND PLANTING**: LoG2 should provide 750-1000 cubic feet of uncompacted soil rooting space dependent on tree species and size. Strategies such as open planting areas, structural cell systems and tree planting trenches with connector spans, root paths, break out zones, or other uncompacted soil volume techniques/ technologies are utilized to maximize soil volume. Ideal growing conditions start with providing adequate soil volumes and space for trees to reach maturity. Tree species are then selected that fit within the above ground space constraints and can tolerate shallow water ponded adjacent to trunks for a short time.

PERFORMANCE:

- 0.6", 2-hr peak flow reduction for a project: 15-40%
- Annual runoff reduction for a project: 10-25%
- Annual runoff reduction for the tributary area: >75%
- Mitigation of average temperature on very hot days: 0.7-4.8°F

CRITERIA:

- Run-on ratio: 2:1 to 6:1
- Canopy coverage at maturity: 40-70% of ROW length, see Chapter 5, section 3 for more information
- Percent WQCV requirement: None
- Surface storage depth: 2"-4"
- Media or Soil: Native or imported suitable for tree growth with an infiltration rate > 0.5 in/hr
- Recommended soil volume: 750-1000 ft^3 / large tree
- Length: 15' (minimum) to 40' (maximum)
- Street Slope: 0.5% (minimum) to 2% (maximum)
- Facility Slope: with grade
- Width: 5' (minimum) to limit of pedestrian route (maximum)
- Spacing: 1 tree every 25 linear feet (ornamental species) to 35 feet (shade species)

Figure 03.01.7: Example of LoG2 - 21st & S. Broadway

[LEVEL OF GREEN 3]

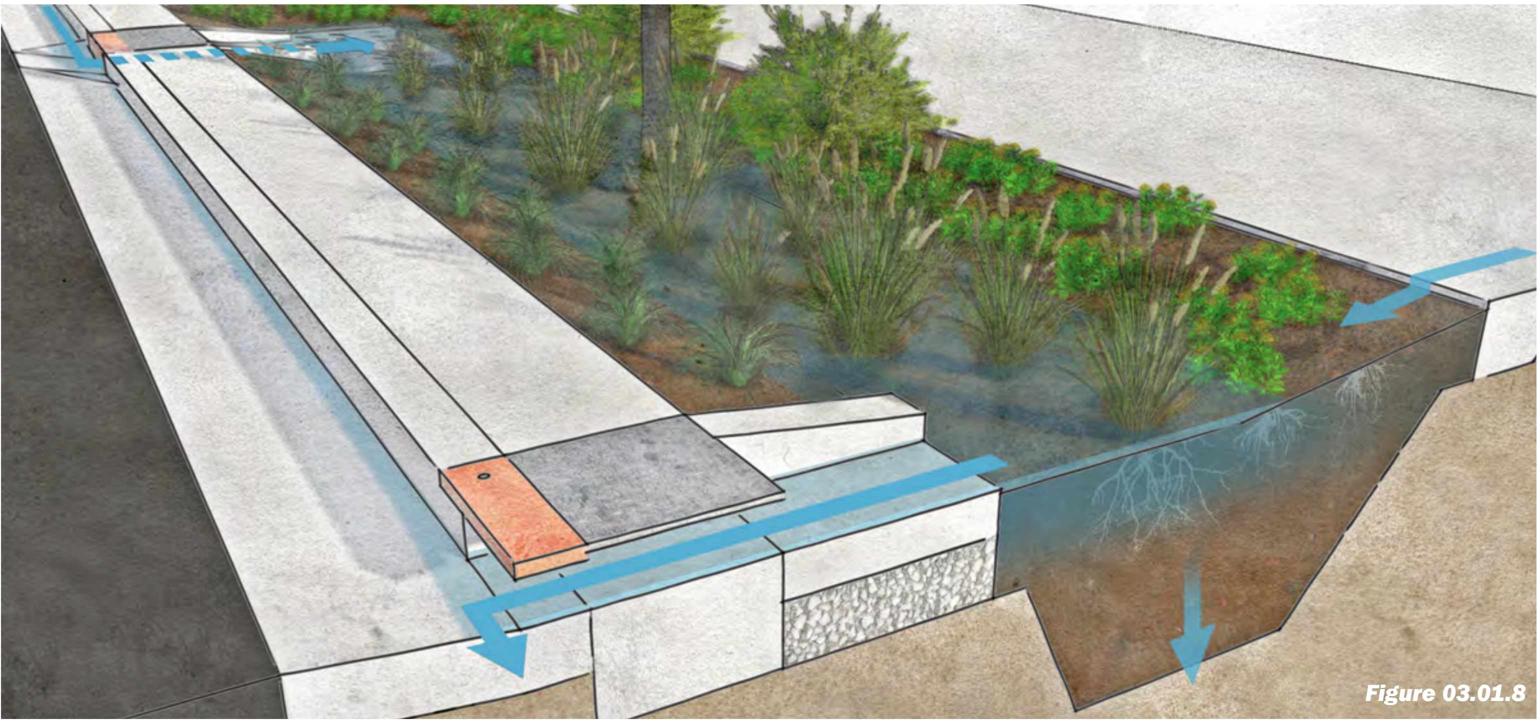


Figure 03.01.8


Figure 03.01.9: Example of LoG3 - Ft. Collins, CO

01.3 - FLOW-THROUGH LANDSCAPES (LOG3)

Level of Green 3 (LoG3) designs build upon the performance of LoG1 and 2 by accepting stormwater runoff from both the roadway and sidewalk/amenity zones into landscaped areas. These flow-through stormwater control measures (SCM) return flows to the roadway curb and gutter conveyance system when the SCM becomes saturated and full. Flow-through facilities slow runoff velocities thereby reducing peak flows and encouraging infiltration as runoff travels through the SCM. Slower stormwater velocities allow pollutants to settle in the media and plants to uptake excess nutrients in the runoff. A major driver for LoG3 implementation is the need to treat roadway runoff wherever possible at a more modest cost when compared to other volumetric approaches.

APPLICATION:

LoG3 designs are ideal in lower-density urban, suburban, and residential areas where the landscaped area is connected to both the roadway and walkway. LoG3 designs require modifications to standard curb and gutter in order to direct roadway runoff to the SCM. Grades between the back of curb and the sidewalk need to be lower than the gutter grade to contain flows and direct them parallel to the roadway's longitudinal grade. Sidewalk grades are naturally directed toward the curb and are thereby intercepted by the SCM. If implemented next to parking or along amenity zones, accommodations should consider vegetation resiliency, ADA compliance and hazards associated with depression depth.

Common applications for LoG3 SCMs include:

- Roadway rehabilitation projects in which curb and gutter are replaced or could be retrofitted to incorporate an inlet to direct storm flows into a recessed landscape area between the curb and sidewalk to create a flow-through facility that returns flows to the gutter pan downstream of the facility;
- Redevelopment and rehabilitation projects, which fall short of triggering regulatory requirements, but afford opportunities to implement green infrastructure in landscape and ROW areas;
- Landscape renovations in existing tree-lawn where dead or dying trees are being removed or replaced or where significant planting renovations are planned; and
- Landscape medians which could be lowered to accept adjacent roadway runoff.

DEFINING CHARACTERISTICS:

The following are characteristics that help define LoG3 and differentiate it from LoG2 and LoG4.

TRIBUTARY: LoG3 SCMs accept runoff from both adjacent roadway and walkway areas.

ENVIRONMENTAL: The flow-through design of an LoG3 SCM is intended to treat flows by reducing velocity, increasing infiltration, and removing sediment/pollutants. Trees can be incorporated into the SCM but should ideally be placed outside the primary flow path. If the ROW width is limited the SCM can be designed more as a landscaped swale with low plantings and grasses.

LoG3 is a SCM more applicable in areas with localized flood risk concerns. The SCM provides a small amount of storage and flow attenuation by intercepting gutter flows and slowing the velocity in the flow-through design. If larger storage volumes are needed, consider combining with LoG4 SCMs.

While LoG3 does provide benefits to urban heat by increasing the vegetated area, it is not the primary goal of this SCM. If urban heat is the primary concern of the location, consider combining with LoG1 or LoG2 SCMs to maximize tree canopy and landscaped area.

STREET USE: LoG3 designs are most appropriate in ROWs with lower pedestrian flows, lower parking turnover and lower urban densities. LoG3 SCMs are not ideal for pedestrians to park next to or cross regularly, for example in between a shopping front and street-side parking. For these reasons LoG3 designs are most applicable in residential, industrial, and mixed-use areas with sufficient space. If the ROW is in an area with high pedestrian traffic, but sufficient width for landscaping, consider LoG2. If the ROW is constrained by limited width, consider LoG4.

VOLUME / DEPRESSION: LoG3 SCMs include a slight depression from the curb flowline in order to contain flows. SCMs do not provide volumetric treatment or storage; rather, it provides rate-based treatment as a flow-through facility.

DRAINAGE INFRASTRUCTURE: LoG3 designs do not include underdrains, nor do they require connections to storm drain systems.

UTILITIES: LoG3 requires some vertical clearance for the depression and gutter flow interception from subsurface utilities. LoG3 may work well where there are subsurface utilities crossing the SCM due to it’s shallow impacts. Due to its continuous nature if there are numerous surface utility impacts such as cabinets, vaults, etc. then a different LoG should be considered.

SOIL MEDIA AND PLANTING: LoG3 utilizes amended in-situ soils or engineered media to promote sustainable vegetation establishment and growth. The criteria detailed in this section is not intended to define a soil depth acceptable for planting and trees, but to provide guidance for amended soil or engineered media over prepared subgrade adequate to provide full soil volumes for all vegetation. Planting strategies should be compatible with the slightly depressed character and occasional inundation.

PERFORMANCE:

- 0.6”, 2-hr peak flow reduction for a project: 30-65%
- Annual runoff reduction for a project: 40-65%
- Annual runoff reduction for the tributary area: >25%
- Mitigation of avg. temperature on very hot days: 0.5-2.9°F

CRITERIA:

- Run-on ratio: 6:1 to 20:1
- Canopy coverage at maturity: 17-35% of ROW length, see Chapter 5, section 3 for more information
- Percent WQCV requirement: None
- Surface storage depth: 1-3” below the gutter flow line
- Media or Soil: Amended in-situ soils or engineered media
- Recommended depth of amended in-situ soil or engineered media: 12-18” min.
- Length: 25’ (min). Max. length is based on site conditions.
- Street slope: 0.5% (min) to 6% (max).
- Facility slope: bottom between 0.5% (min) to 2% (max), using weir wall components to limit grade.
- Minimum width: 5’ (for trees) or 3’ (for grasses / shrubs)
- Spacing: Dependent on run-on ratios

[LEVEL OF GREEN 4]

Figure 03.01.10

01.4 - INFILTRATING CONTROL MEASURES (LOG4)

Level of Green 4 (LoG4) stormwater control measures (SCM) include surface and subsurface components intended to detain, treat, and infiltrate or release runoff intercepted from impervious surfaces. LoG4 control measures are shallow recessed landscape areas that utilize structural systems to attenuate stormwater flows and provide peak flow reduction while maximizing filtration and infiltration capacities.

LoG4 control measures are designed to store at least 60% of the regulatory water quality capture volume (WQCV). This allows for larger tributary areas and/or smaller footprints than full WQCV SCMs, which may be beneficial in constrained areas. A storage volume of 60% of the WQCV is capable of infiltrating 75% WQCV when infiltration rates into the native subgrade are at least 1.0 in/hr and the SCM does not contain an underdrain. Therefore, LoG4 control measures generally do not include an underdrain system to prioritize infiltration and runoff reduction. A partial or full liner and underdrain system may be necessary in areas with high groundwater tables, nearby basements or below grade parking and in areas with high levels of subgrade pollution.

APPLICATION:

LoG4 designs are ideal in higher-density urban, multi-use, and commercial areas where the landscaped area is connected to both the roadway and walkway. Because stormwater depths in the street increase

Figure 03.01.11: Example of LoG4 - Brighton Blvd.

as runoff travels downstream, LoG4 designs may benefit by being located in middle or upper portions of sub-basins prior to significant flow accumulation, in areas experiencing localized flooding, or in combination with other levels-of-green to help reduce impacts on gray collection and conveyance infrastructure. LoG4 control measures may also be used on projects that have a regulatory requirement for water quality control by meeting the Runoff Reduction pathway specified in Denver's MS4 permit which requires an SCM to infiltrate 75% of the WQCV. LoG4 should only be used to meet this pathway after analysis shows infiltration rates of native subgrade are sufficient (>1 in/hr minimum, >2 in/hr preferred). Consider utilizing underdrains if infiltration rates are lower.

LoG4 designs may require modifications to standard curb and gutter in order to direct roadway runoff to an SCM. LoG4 SCMs can be implemented in areas where the ROW width is too limited for LoG3 facilities and where SCMs can be separated and spaced to allow for better pedestrian movements between facilities. The engineering and construction for LoG4 is more rigorous, however provides greater benefits to peak-flow reduction and water quality. A storm drainage connection should be within reasonable proximity to the SCM if a connected underdrain is required when full infiltration is not viable. If implemented next to parking, bus stops, or along amenity zones and step out zones an SCM should be located considering ADA compliance and hazards associated with facility depth.

Common applications for LoG4 SCMs include:

- Roadway rehabilitation projects in which curb and gutter are replaced or could be retrofitted to incorporate an inlet to direct storm flows into a recessed landscape area between the curb and sidewalk; and
- Large pipe replacement, rehabilitation, or repair projects

DEFINING CHARACTERISTICS:

The following are characteristics of LoG4 and differentiate it from LoG3 and LoG5.

TRIBUTARY: LoG4 SCMs accept runoff from both adjacent roadway and walkway areas.

ENVIRONMENTAL: The engineered design is intended to treat flows by reducing runoff volumes, increasing infiltration, detaining a portion of the water quality event and removing sediment/pollutants. LoG4 is an SCM most applicable in areas with localized flood risk concerns. While LoG4 does provide benefits to urban heat by increasing the vegetated area, it is not the primary goal of this SCM. If urban heat is the primary concern of the location, consider combining with LoG1 or 2 to maximize tree canopy and landscaped area.

STREET USE: LoG4 designs are most appropriate in ROWs with higher pedestrian flows, higher parking turnover and higher urban densities. LoG4 SCMs can be sited for pedestrians to park next to or cross semi-regularly.

VOLUME / DEPRESSION: LoG4 SCMs include depression from the curb flowline in order to contain flows. SCMs provide volumetric treatment or storage in accordance with MHFD guidelines.

DRAINAGE INFRASTRUCTURE: LoG4 designs can include underdrains or can be full infiltration facilities depending on soil conditions and proximity to other infrastructure. Thus, LoG4 facilities could be sited near existing storm drain systems, but is not required.

UTILITIES: LoG4 requires vertical clearance for storage and engineered components. LoG4 is most applicable in locations where there may be numerous surface utilities around the SCM, but few subsurface conflicts. If there are numerous subsurface utility impacts such as water, sanitary, etc. then a different LoG should be considered.

SOIL MEDIA AND PLANTING: LoG4 utilizes engineered media to promote sustainable vegetation establishment and growth. Planting strategies should be compatible with the slightly depressed character and frequent inundation.

PERFORMANCE:

- 0.6", 2-hr peak flow reduction for a project: 30-60%
- Annual runoff reduction for a project: 30-45% (50-75% without underdrains)
- Annual runoff reduction for the tributary area: >25% (>60% without underdrains)
- Mitigation of avg. temperature on very hot days: 0.3-2.4 ° F

CRITERIA:

- Run-on ratio: < 45:1
- Canopy coverage at maturity: 11-17% of ROW length, see Chapter 5, section 3 for more information
- Percent WQCV requirement: 60% - 80%
- Surface storage depth: 3"-6"
- Media or Soil: As specified by MHFD, Subgrade infiltration rates >1.0 in/hr (min), but prefer >2.0 in/hr, otherwise use an underdrain.
- Recommended depth of engineered media: 18"-36"
- Length: 15' (minimum) to 40' (maximum)
- Street slope: 0.5% (min) to 6% (max).
- Facility slope: bottom between 0.5% (min) to 2% (max), using weir wall components to limit grade.
- Width: 5' (minimum) to 15' (maximum)
- Spacing: Dependent on run-on ratios

[LEVEL OF GREEN 5]

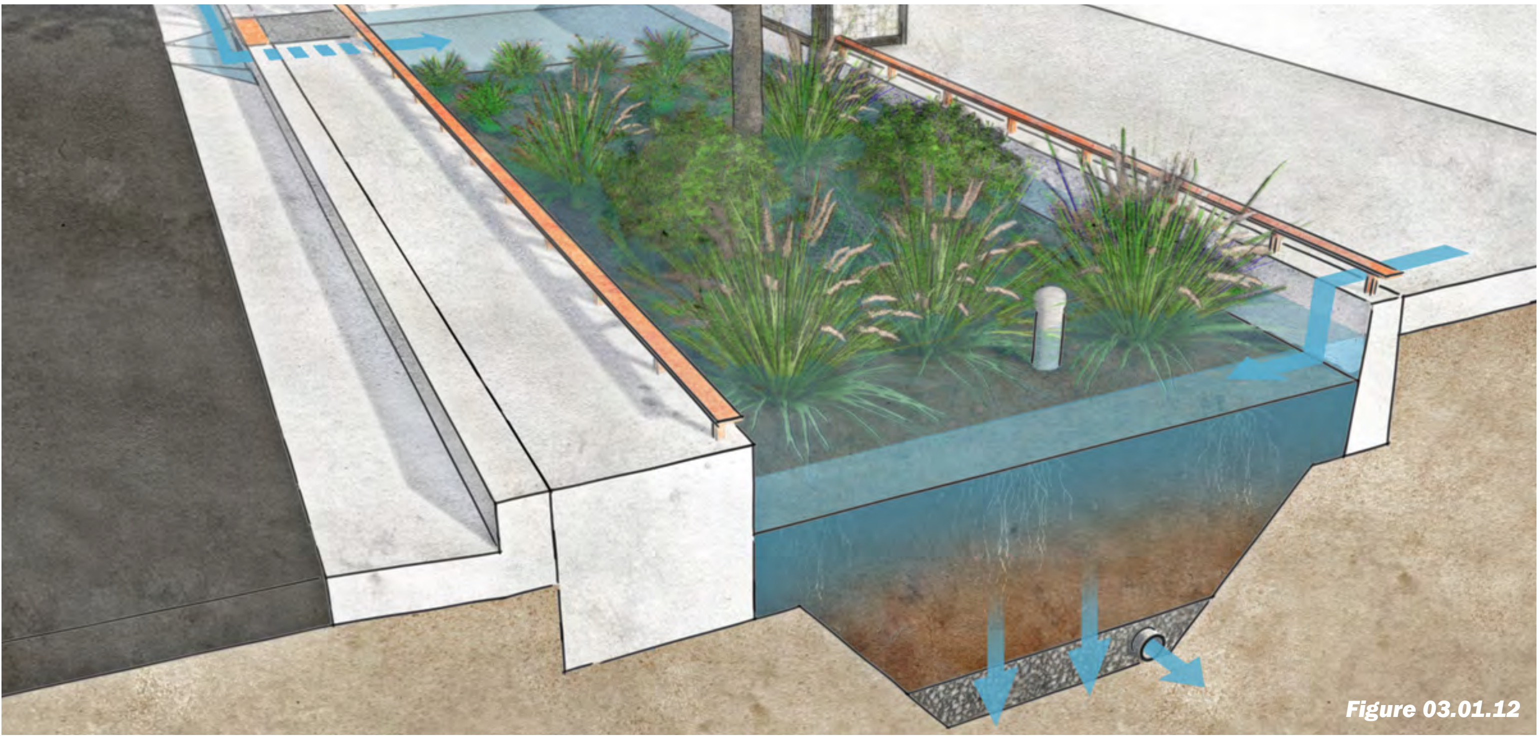


Figure 03.01.12

Figure 03.01.13: Example of LoG5 - Brighton Blvd.

01.5 - VOLUME CAPTURE CONTROL MEASURES (LOG5)

Level of Green 5 (LoG5) design utilizes engineered stormwater control measures (SCM) as defined in the City and County of Denver *Ultra-Urban Green Infrastructure Guidelines* and Mile High Flood District's *Urban Storm Drainage Volume 3* to manage stormwater to meet regulatory requirements.

LoG5 control measures are designed to manage 100% of the regulatory water quality capture volume (WQCV). Underdrains are typically used with LoG5 SCMs to meter and control runoff rates and volumes, however full infiltrating sections without underdrains may also be possible if subsurface soil conditions are favorable for infiltration.

APPLICATION:

LoG5 SCMs should be utilized when there is a regulatory requirement for 100% WQCV or when a project is in a high priority water quality basin. LoG5 designs are detention or bioretention facilities that manage flows according to regulatory requirements. LoG5 control measures require rigorous engineering to calculate and design for the WQCV as well as sufficient area in the ROW to implement the more complex facility. Streetside Stormwater Planters (SSPs) and Curb Extensions are typical applications of an LoG5 SCM and further design guidance and criteria can be found in the City and County of Denver *Ultra Urban Green*

Infrastructure Guidelines. If implemented next to parking lanes, bus stops, or along amenity zones or step out zones accommodations should consider ADA compliance and hazards associated with facility depth.

Common applications for LoG5 control measures include:

- Construction of new roadways, roadway widening or roadway rehabilitation projects that trigger regulatory requirements;
- Large pipe replacement, rehabilitation, or repair projects; and
- Significant redevelopment or rehabilitation of roadways/alleys/walkways.

DEFINING CHARACTERISTICS:

The following are characteristics of LoG5 and differentiate it from the other levels.

TRIBUTARY: LoG5 SCMs accept runoff from both adjacent roadway and walkway areas.

ENVIRONMENTAL: The engineered design is intended to treat flows by reducing runoff, increasing infiltration or filtration, detaining the water quality event and removing sediment/pollutants.

While LoG5 can provide benefits to urban heat by increasing the vegetated area, it is not the primary goal of this control measure. If urban heat is the primary concern of the location, consider combining with LoG1-3 SCMs to maximize tree canopy and landscaped area.

STREET USE: LoG5 designs are most appropriate when there is a regulatory requirement and sufficient width in the rights-of-way. LoG5 SCMs are ideal in areas with controlled pedestrian movements, lower parking turnover and higher urban densities.

VOLUME / DEPRESSION: LoG5 control measures include a depression from the curb flowline in order to contain flows. Control measures provide volumetric treatment and storage in accordance with Mile High Flood District guidelines.

DRAINAGE INFRASTRUCTURE: LoG5 designs can include underdrains that require connections to storm drain systems. If subgrade infiltration rates exceed 3-inches per hour, it may require modifications to the design for the underdrain to lengthen residence time so that stormwater is available for uptake by plant material.

UTILITIES: LoG5 requires vertical clearance for storage and engineered components. LoG5 may require additional considerations in locations where there are numerous surface or subsurface utilities around the control measure. Utilities may need to moved outside the footprint of the SCM, lowered below the bottom of the SCM and sleeved, or sleeved if the existing utility is below the bottom fo the SCM.

SOIL MEDIA AND PLANTING: LoG5 utilizes engineered media to promote filtration while also trying to establish sustainable vegetation. Faster subgrade infiltration rates may require a modification to the underdrain; see Drainage Infrastructure, above. Planting strategies should be compatible with the depressed character and frequent inundation.

PERFORMANCE:

- 0.6”, 2-hr peak flow reduction for a project: >80%
- Annual runoff reduction for a project: 40-50% (70-80% without underdrains)
- Annual runoff reduction for the tributary area: >40% (>70% without underdrains)
- Mitigation of avg. temperature on very hot days: 0.3-1.8°

CRITERIA:

- Run-on ratio: < 35:1
- Canopy coverage at maturity: 11-17% of ROW length, see Chapter 5, section 3 for more information
- Percent WQCV requirement: 100%
- Surface storage depth: 6”-9”
- Media or Soil: As specified by MHFD
- Recommended depth of engineered media: 18”-36”
- Length: 15’ (minimum) to 40’ (maximum)
- Street slope: 0.5% (min) to 6% (max)
- Facility slope: bottom between 0% (min) to 2% (max), using weir wall components to limit grade.
- Width: 5’ (minimum) to 15’ (maximum)
- Spacing: Dependent on run-on ratios

02 - HYDROLOGIC PERFORMANCE & CRITERIA ANALYSIS

02.1 - INTRODUCTION AND SUMMARY

An important underpinning of the *Green Continuum: Streets* is that the design criteria and hydrologic performance used to define the Levels of Green is based in robust quantitative analysis. Similar analysis is also used to quantify the canopy coverage and heat mitigation benefits for each of Level of Green. This allows users of the *Green Continuum: Streets* to compare stormwater control measure (SCM) design options objectively with confidence. This section gives a summary of that quantitative analysis, which can be found in full detail in Appendix 3.

The first phase of the analysis involved identifying potential SCMs and integrating them into a typical street cross section based on existing design criteria. The SCMs were then simulated in EPA-SWMM (an urban runoff model) to quantify hydrologic performance. Performance was used to define each of the Levels of Green initially. The second phase involved establishing ranges of key design criteria for each of the Levels of Green based on the ability to reduce runoff from its direct tributary area. Finally, the third phase identified ranges of canopy coverage and quantified reductions in temperature using SOLWEIG (an outdoor thermal comfort model) that each Level of Green could provide to a typical right-of-way (ROW). The results of three phases are summarized in Table 03.02.1.

02.2 - HYDROLOGIC MODELING THE LEVELS OF GREEN

PURPOSE

The purpose of the hydrologic analysis was to identify potential SCMs and to use hydrologic modeling results to classify each SCM into one of the levels Level of Green. The classification is driven by simulated hydrologic performance, including runoff reduction over a 10 year period and peak flow reduction of the water quality design storm.

METHODS

The first phase of the analysis involved identifying a list of potential stormwater control measures (SCMs) and integrating them into a synthetic 400’ long x 80’ wide ROW. The SCMs considered were pervious, landscape areas located in the ROW between the curb and the walkway (Figure 03.02.01). The number, footprint area, surface storage depth, and media depth was systematically varied to come up with an exhaustive list of SCM designs. The hydrologic connectivity was also varied such that the SCMs were either able to receive flow from just the walkway or the walkway plus the drive lanes of the road. Finally, some SCMs were considered to have underdrains, if appropriate.

Figure 03.02.01 summarizes how the SCMs designs were varied in terms of hydrologic connectivity, surface storage depth, and media depth.

Level of Green	**Project-level performance**			**SCM-level performance**	**Design Criteria**			
	Water quality storm peak flow reduction [%]	Annual runoff reduction [%]	Heat Mitigation Benefits [F]	Annual runoff reduction of direct tributary area [%]	Run-on Ratio [tributary area : SCM area]	Volume Storage Requirement [% WQCV]	Surface storage Depth [in]	Media or soil Depth [in]
1	5 to 15	5 to 10	1.1 to 6.7 °F	>75	1 to 3	NA	0	Supports tree growth
2	15 to 40	10 to 25	0.7 to 4.8 °F	>75	2 to 6	NA	2 to 4	Supports tree growth
3	30 to 65	40 to 65	0.5 to 2.9 °F	>25	6 to 20	NA	0 to 4	6 to 18
4	30 to 60	30 to 45 (50 to 75 w/o underdrain)	0.3 to 2.4 °F	>30 (>60 w/o underdrain)	≤ 45	60	3 to 6	6 to 36
5	>80	40 to 50 (70 to 80 w/o underdrain)	0.3 to 1.8 °F	>40 (>75 w/o underdrain)	≤ 35	100	6 to 9	18 to 36

Table 03.02.1: Summary of quantitative analyses described in this section

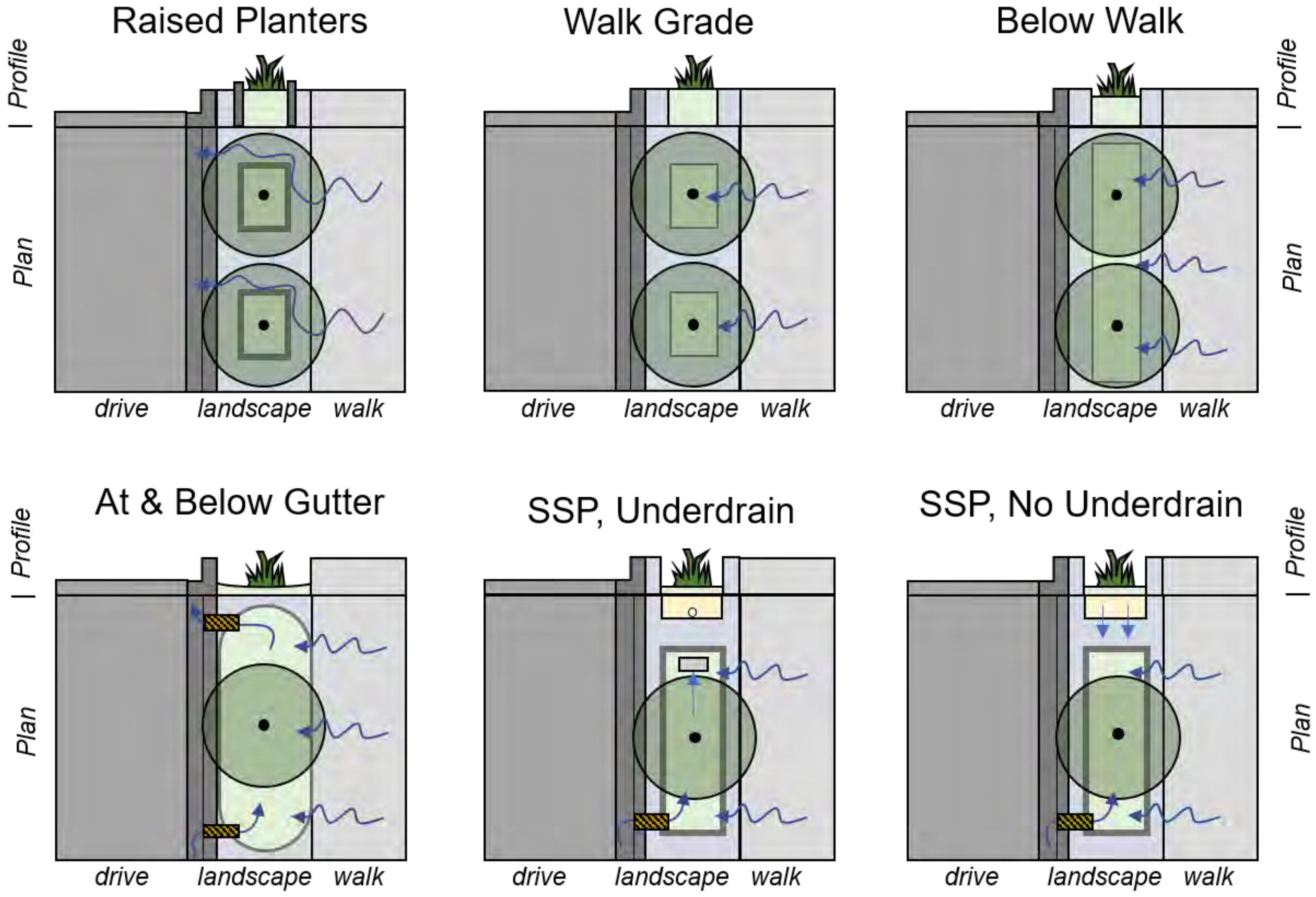


Figure 03.02.1: Graphical guide for understanding the pervious stormwater control measure configurations in the typical right-of-way. "SSP" stands for streetside stormwater planter – a more heavily engineering bioretention facility that is commonly used in Denver

RESULTS

The 26 SCM configurations were then integrated into the urban runoff model to determine hydrologic performance, quantified as the percent reduction of a 2-yr storm peak flow and annual runoff reduction over a 10 year continuous simulation. Figure 03.02.2 shows the results for peak flow reduction and annual runoff reduction for all 26 SCM configurations. The results were synthesized into five findings that helped to define the Levels of Green. These findings were:

FINDING 1: Reductions in peak flow and runoff improve linearly relative to the pervious added in the ROW if that pervious area has no tributary area besides itself.

FINDING 2: Routing runoff from the walkway to adjacent pervious landscapes (even if there is no surface storage on the landscape) improves runoff and peak flow reduction by ~3x compared to when the landscapes are not able to receive walkway runoff.

FINDING 3: Runoff reductions improve by 3-4x when routing runoff from the road and walkway to pervious areas compared to routing only runoff from the walkway to the same pervious area.

FINDING 4: Depressing pervious areas draining runoff from the road increases performance considerably.

FINDING 5: SCMs without underdrains outperform those with underdrains for runoff reduction.

These findings were used to identify design practices that lead to notable differences in performance which therefore define each Level of Green. Based on this definition, each of the 26 configurations were classified into a Level of Green as shown with the color scale in Figure 03.02.2, and reasonable ranges of hydrologic performance ranges were determined for each Level of Green (Table 03.02.2).

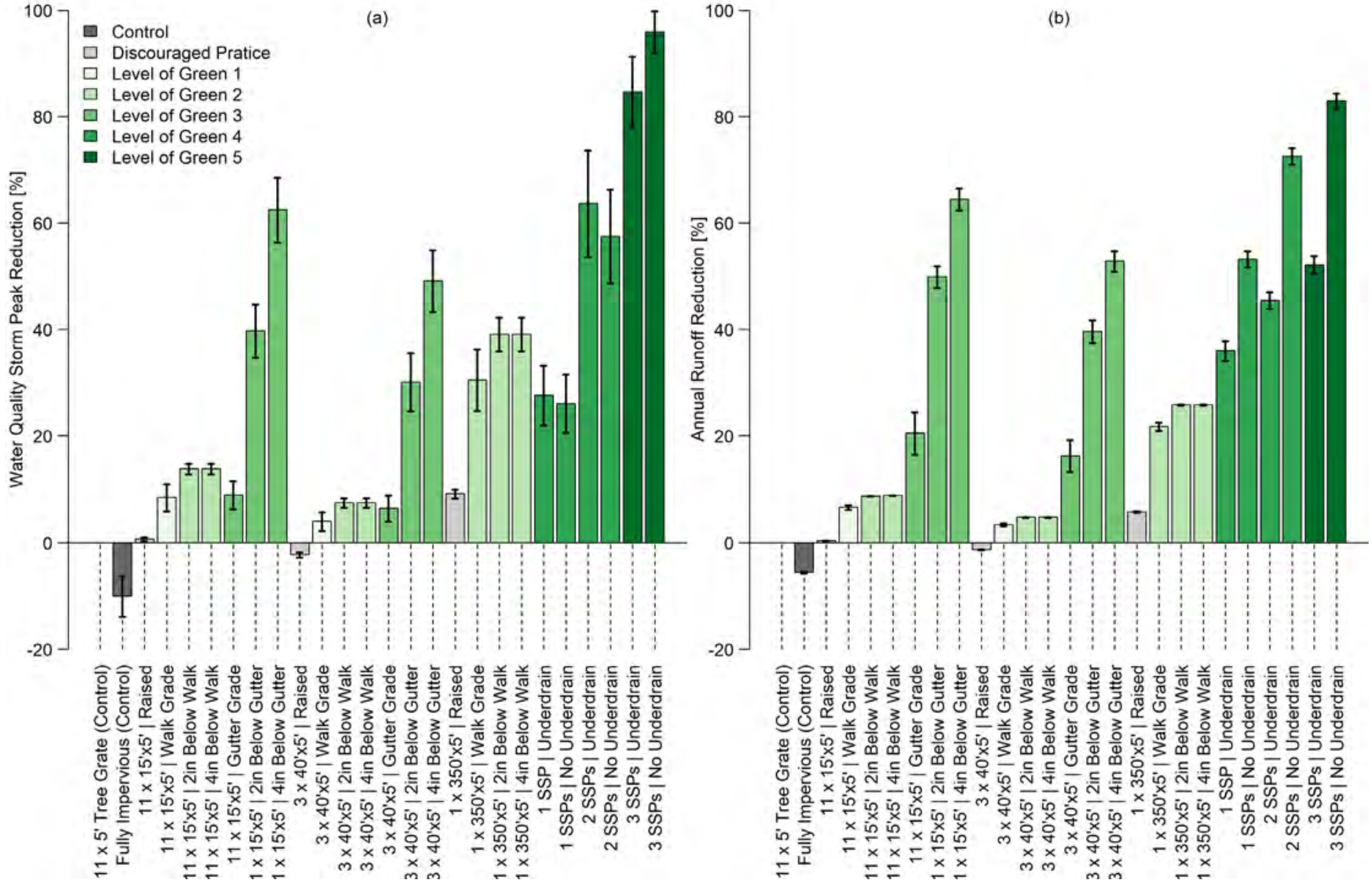


Figure 03.02.2: Percent reductions in (a) a 2-yr water quality storm's peak flow and (b) annual runoff reduction measured relative to a control simulation with 11 5'x5' tree grates.

Level of Green	**Practice**	**Findings Supporting Practice**	**Water quality storm peak flow reduction [%]**	**Annual runoff reduction [%]**
1	Maximize pervious landscape area in the right-of-way	Finding 1	5 to 15	5 to 10
2	Route walkways to pervious landscape area	Finding 2	15 to 40	10 to 25
3	Route walkways and roads to pervious landscape areas	Finding 3	30 to 65	40 to 65
4	Provide partial volume storage (avoid underdrains if possible)	Findings 4 and 5	30 to 60	20 to 45 (50 to 75 w/o underdrains)
5	Provide full volume storage, per local regulatory requirements	NA	>80	40 to 50 (70 to 80 w/o underdrains)

Table 03.02.2: Initial Levels of Green Description and Performance Ranges

02.3 - ESTABLISHING STORMWATER CONTROL MEASURE DESIGN CRITERIA

PURPOSE

The purpose of this analysis is to establish design criteria for control measures in each Level of Green based on their ability to reduce runoff, as simulated by a hydrologic model. The design variables considered for the criteria are soil classification, run-on ratio, longitudinal slope, media/soil depth, and surface storage depth.

METHODS

For each Level of Green, continuous modeling of 10 years of rainfall and runoff in EPA-SWMM was used to quantify annual runoff reduction across the soil classification, run-on ratio, longitudinal slope, media/soil depth and surface storage depth ranges shown in Table 03.02.03. From there, a minimum runoff reduction performance standard was selected for each Level of Green, and design criteria were identified that achieves that performance standard at least 75% of the time.

RESULTS

Based on the model results anticipated runoff reduction for the direct tributary area can be expected to be >75% for Levels of Green 1 and 2 and >25% for Level of Green 3. While the Level of Green 3 performance threshold is 3x lower than Levels 1 and 2, the SCM is designed to manage much larger tributary areas which can lead to greater volume reductions overall. Levels of Green 4 and 5 are defined by a volume standard which is related to tributary area, so there is no need to establish additional design criteria. The performance threshold is >60% runoff reduction for Level of Green 4 and >40% for Level of Green 5 based on the volume standard. The established design criteria and performance thresholds are shown in Table 03.02.04.

Level of Green	**Soil Infiltration Rate**		**Run-on Ratio**			**Surface Storage [in]**			**Slope [%]**			**Media Storage [in]**		
	Fast	Slow	Low	High	Step	Low	High	Step	Low	High	Step	Low	High	Step
1	C/D	C/D	2	4	1	0	1	1	1	8	1	NA	NA	NA
2	C/D	C/D	2	9	1	0	4	1	1	8	1	NA	NA	NA
3	C/D	C/D	10	50	5	0	4	1	1	8	1	NA	NA	NA
4	1.0 in/hr	0.5 in/hr	10	45	5	3	6	1	1	8	1	6	36	6
5	1.0 in/hr	0.5 in/hr	10	35	5	6	9	1	1	8	1	6	36	6

Table 03.02.03: Ranges of design variables simulated in SWMM for each Level of Green

Level of Green	**SCM-level performance threshold**	**Design Criteria**			
	Annual runoff reduction of direct tributary area [%]	Run-on Ratio [tributary area : SCM area]	Volume Storage Requirement [% WQCV]	Surface storage Depth [in]	Media or soil Depth [in]
1	>75	1 to 3	NA	0	NA
2	>75	2 to 6	NA	2 to 4	NA
3	>25	6 to 20	NA	0 to 4	6 to 18

Table 03.02.04: Design criteria and minimum SCM runoff reduction for each Level of Green

03 - QUANTIFYING HEAT MITIGATION

PURPOSE

The purpose of the third phase of the analysis was to estimate urban heat mitigation benefits in the right-of-way provided by trees planted in the stormwater control measures (SCM) for each Level of Green.

METHODS

The first step of the analysis was to use the design criteria generated in the previous hydrologic modeling exercises along with forestry standard practices to estimate a high and low number of trees that may be planted for each Level of Green in a typical 400' long right-of-way. Next, the cooling benefits associated with these number of trees was determined using thermal comfort modeling. This was done by creating a 400' long by 80' wide synthetic right-of-way area for analysis and including adjacent private property buildings impact on shade and shadow(Figure 03.02.3). The synthetic right-of-way was arranged in 46 different configurations that span the Levels of Green and account for variability in street orientation (East/West vs. North/South) and adjacent land use (Downtown, Commercial, or Residential buildings). The Solar and LongWave Environmental Irradiance Geometry (SOLWEIG)^2 model then simulated mean radiant temperature (MRT) in the right-of-way for each of the 46 different configurations. MRT is a measure of outdoor thermal comfort that accounts for the sun's radiation in addition air temperature, wind speed, and humidity.

RESULTS

The range in the numbers of trees, justification for selection, and the resulting canopy coverage for each Level of Green are shown in Table 03.02.05. The high and low number trees in Table 03.02.05 (0, 2, 3, 5, 8, 11 per street side per 400 linear feet) were then modeled in SOLWEIG to determine the average daily heat mitigation benefits in the walkway and bike lane sections of a typical right-of-way. The range in cooling benefits associated with each Level of Green is also shown in Table 03.02.05. The range is due to variations in street orientation and adjacent building type. A detailed analysis of the effects of street orientation and adjacent land use can be found in Appendix 3.03.

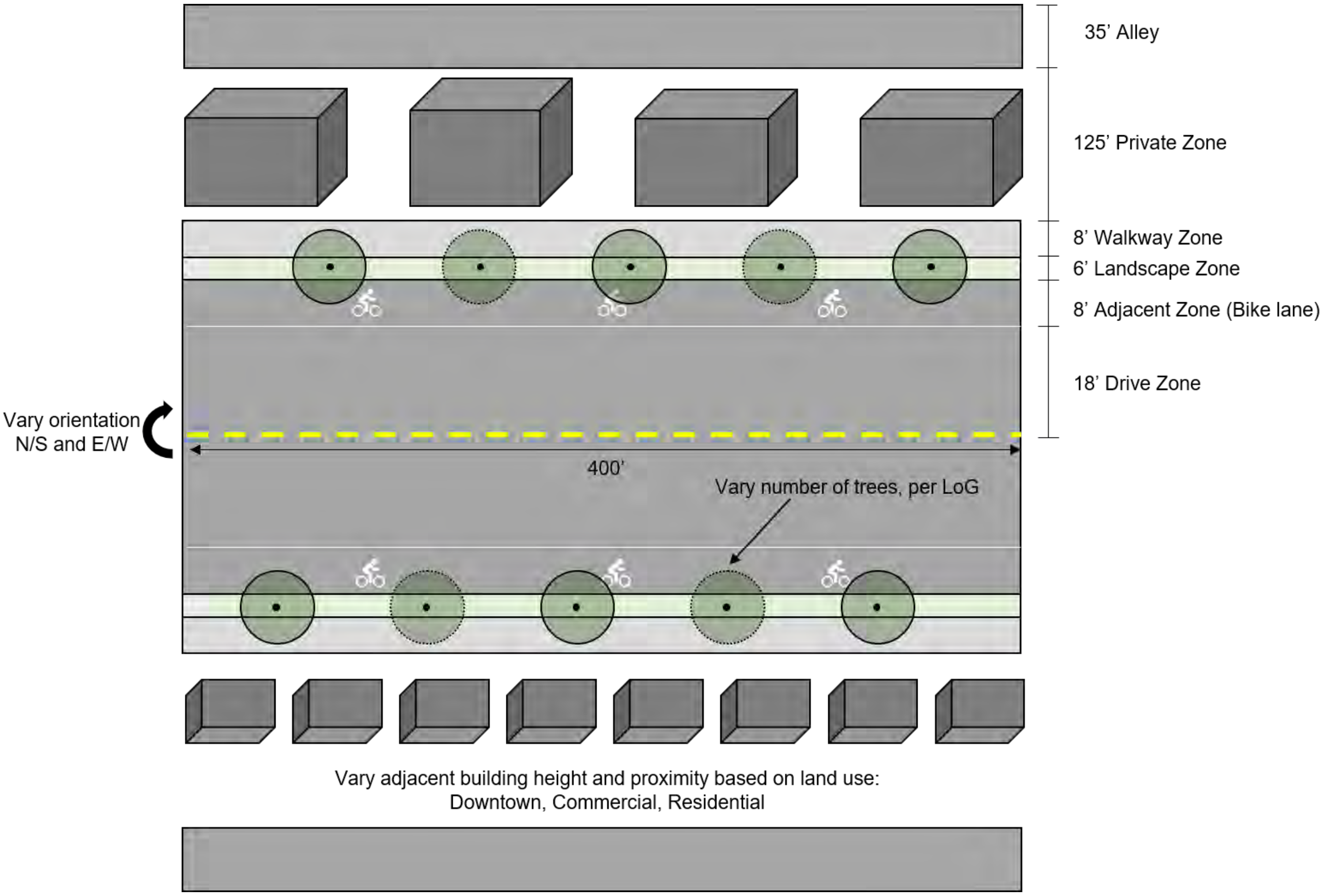


Figure 03.02.3 Diagram of the model SOLWEIG domain and summary of the simulations (not to scale)

Level of Green	Range in number of trees	Range in canopy coverage [%]	Justification for selection of the number of trees for each Level of Green	Heat Mitigation Benefits [°F MRT]
1	8 to 11	70 to 95	8 = 75th percentile of existing number of trees / 400’ city block 11 = Maximum given 30’ minimum tree spacing requirements	1.1 to 6.7
2	5 to 8	40 to 70	5 = Median existing number of trees / 400’ city block 8 = Maximum amount given 1 tree / 40’ long planter (+4’ spacing)	0.7 to 4.8
3	3 to 4	17 to 35	3 = One fewer SCM* than 4 (the number of SCMs described below) Number of 40’x5’ SCMs needed to treat the 400’ street at 20:1 run-on ratio	0.5 to 2.9
4	2 to 3	11 to 17	2 = Low number of SCMs needed to treat 60% of the WQCV for a 400’ street 3 = High number of SCMs needed to treat 60% of the WQCV for a 400’ street	0.3 to 2.4
5	2 to 3	11 to 17	2 = Low number of SCMs needed to treat 100% of the WQCV for a 400’ street 3 = High number of SCMs needed to treat 100% of the WQCV for a 400’ street	0.3 to 1.8

*Assumes 1 tree planted / SCM

Table 03.02.05: Canopy coverage and heat mitigation benefits for each Level of Green

ENDNOTES

1 City and County of Denver. *Green Infrastructure Implementation Strategy*. 2018. Web. https://www.denvergov.org/content/denvergov/en/wastewater-management/stormwater-quality/green-infrastructure/implementation.html

2 Lindberg, F.; Holmer, B.; Thorsson, S. SOLWEIG 1.0 - *Modelling Spatial Variations of 3D Radiant Fluxes and Mean Radiant Temperature in Complex Urban Settings*. Int. J. Biometeorol. 2008, 52 (7), 697–713. https://doi.org/10.1007/s00484-008-0162-7.

Chapter FOUR

CONTROL MEASURES & COMPONENTS

01 - DESIGN STRATEGIES

The previous chapter outlined each Level of Green (LoG) and identified key performance criteria that separate each level. In this chapter, each LoG is further defined as stormwater control measures (SCM) and components. Each of the SCMs is an aggregate of components that are developed to meet performance criteria for stormwater, heat, and equity goals and objectives. Components are key individual parts of the SCM and can be mixed and matched to help achieve both the performance criteria as well as aesthetic or other key design-related goals.

The control measures and components defined in sections two and three of this chapter are examples to help aid the designer in developing a comprehensive design approach for a project. Control measures and components discussed in this chapter are illustrated to foster creative solutions for the following:

- (LoG1) At-grade, high-performing landscapes with adequate soil volumes to support a high quality tree canopy;
- (LoG2) Shallow infiltrating landscapes managing runoff from small areas;
- (LoG3) Flow-through stormwater landscapes;
- (LoG4) Recessed, infiltrating stormwater control measures capable of meeting regulatory water quality treatment and runoff reduction; and
- (LoG5) Volume capture stormwater control measures capable of meeting regulatory requirements (WQCV)

Design teams are encouraged to expand on the concepts detailed in this chapter for SCMs and to develop new approaches that meet the site-specific criteria for each project. As new concepts are explored the design teams should work with City agencies such as DOTI, Development Services, Parks & Recreation, or any other appropriate agency responsible for permitting and approving SCMs to ensure they can be built within the public rights-of-way.

Each of the following example SCMs outline the primary benefits and functions for a control measure as well as the ideal Level of Green where that example SCM should be used.

The SCMs detailed below are not intended to be an all-inclusive list but to act as an inspiration for the designers to develop similar or new approaches that meet project-specific goals as well as critical design criteria outlined in the Chapter 3, Levels of Green.

02 - STORMWATER CONTROL MEASURES

The *Ultra Urban Green Infrastructure Guidelines* (UUGIG) established a set of stormwater control measures that were appropriate for use in ultra-urban areas and intended to manage the water quality capture volume (WQCV). Many of the SCMs detailed in the UUGIG are appropriate for use as LoG4 and LoG5 facilities.

The Green Continuum: Streets expands the ranges and types of stormwater control measures that can span the different Levels of Green with minor changes to components and configurations.

The following pages have eleven example SCMs that are shown in a single configuration for illustrative purposes. Each example SCM includes a graphic at the bottom of the header image indicating the ideal LoG for the shown approach:

LoG1	Control Measure Appropriate for LoG
LoG1	Control Measure Acceptable for LoG, but may have special considerations
LoG1	Control Measure Not recommended for LoG

Many SCMs can work in several Levels of Green with some minor adjustments to the design or by changing components to achieve specific criteria based on the target Level of Green.

Each SCM also includes a compatibility matrix which indicates which components are appropriate, acceptable under certain circumstances, or not recommended:

🟢	Component Type appropriate for Control Measure
🟠	Component Type acceptable for Control Measure, but may have special considerations
○	Component Type not applicable to Control Measure

[TREE CANOPY]

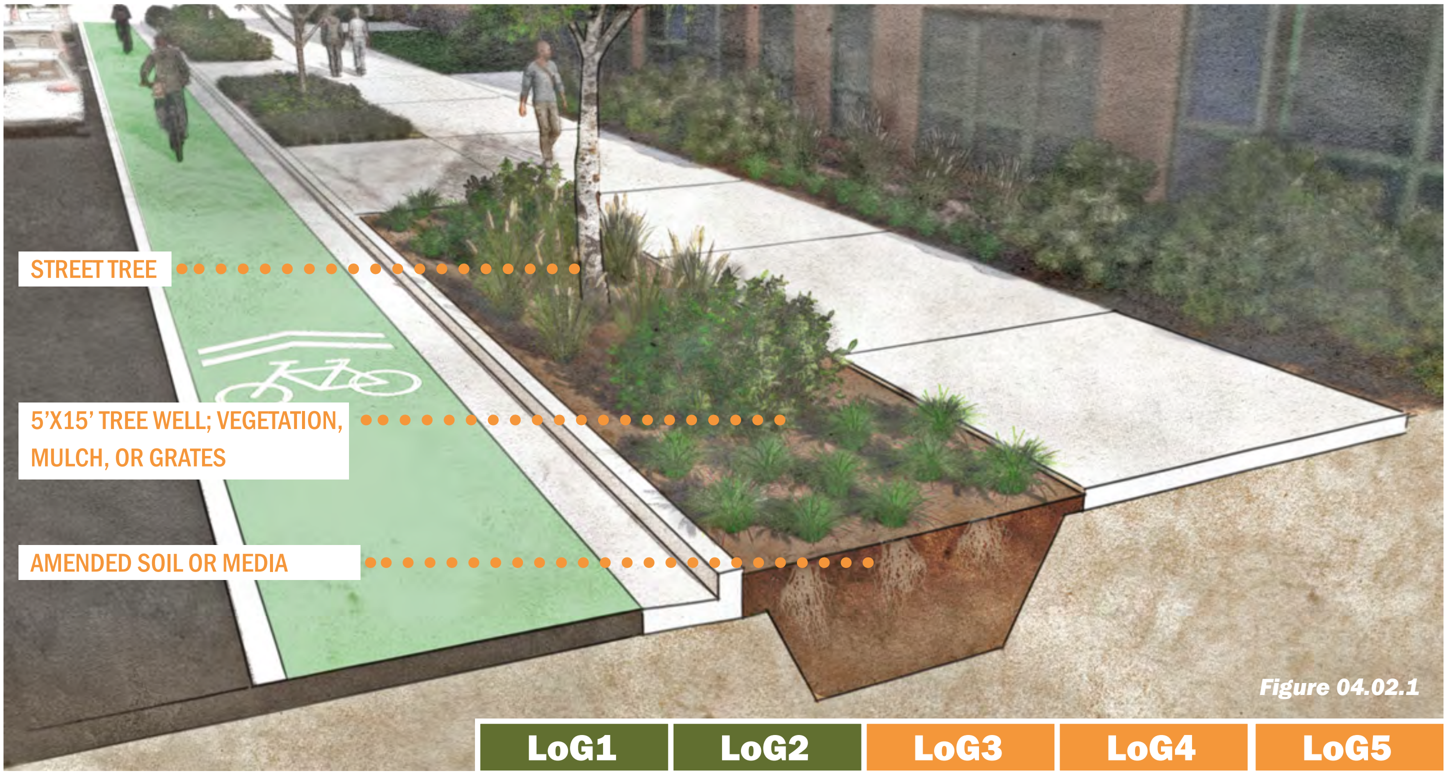


Figure 04.02.1

02.1 - TREE CANOPY

The canopy of leaves on mature trees is one of the best stormwater management and heat mitigation tools in the urban environment. Dense canopy contributes significantly to pedestrian comfort through cover and shade. The tree canopy is also very effective at intercepting rainfall and providing stormwater runoff reduction benefits.

Trees are a critical part of all five Levels of Green and should be considered in all stormwater control measures (SCM). LoG1 and LoG2 are primarily focused on the creation of healthy urban tree canopy through providing adequate soil volumes and SCM configurations that capture small volumes of stormwater for infiltration and uptake by the trees roots. LoG3 through LoG5 include trees as a critical component, but also have unique requirements for soil mixes, soil depths, subgrade preparation and anticipated hydroperiods for stormwater inundation that will impact trees sizes and species.

Trees need adequate volumes of oxygen and nutrient rich soil to thrive, which is even more critical in an urban environment. The Office of City Forester (OCF) has recommended soil volumes for trees; 750 CF for small and medium trees and 1000+ CF for large trees.

Components		Suitable Types					
		A	B	C	D	E	F
1	Inlet	○	○	○	○		
2	Forebay	🟠	🟠	○	○	○	○
3	Grade Control	🟢	🟠	○	○	🟢	🟢
4	Edge Barrier	🟢	🟢	🟠	🟢	🟠	
5	Subsurface	○	○	🟠	🟢	○	
6	Overflow	○	○	○	○	○	
🟢	Appropriate	🟠	Appropriate w/ conditions	○	Not Applicable		

The impact of adequate soil is critical in bioretention as soils improve retention of dissolved phosphorous and nitrogen, allows trees to grow larger root systems which also keeps media loose for better infiltration.

[TREE LAWN SWALE]

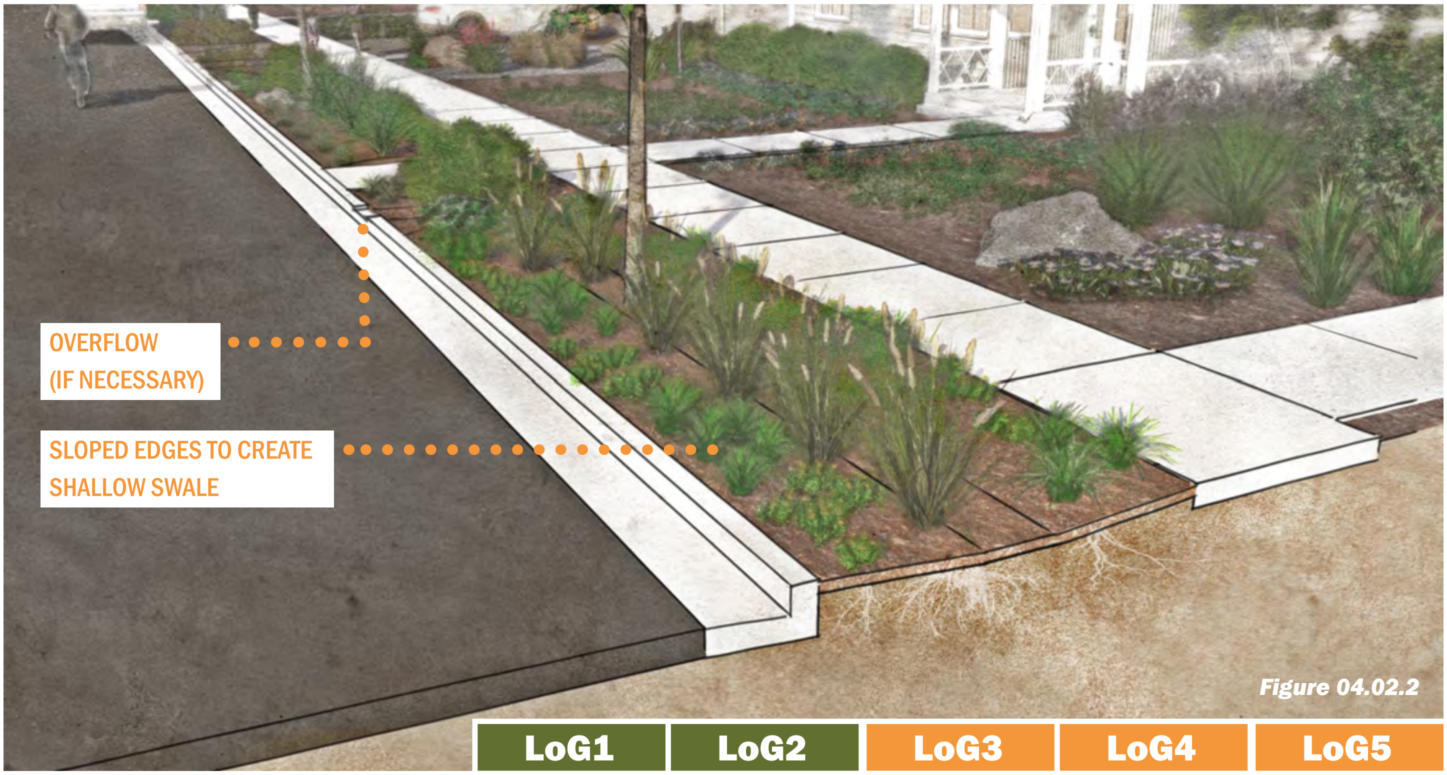


Figure 04.02.2

02.2 - TREE LAWN SWALE

Tree lawns in residential and industrial areas are often underutilized landscapes in the public right-of-way. The Tree Lawn Swale is included as a low-cost, simple, non-engineered control measure intended to provide shallow storage for stormwater runoff from sidewalks or incidental runoff from adjacent properties.

These low impact control measures can be installed in neighborhoods and blend in with typical ornamental or lawn landscapes. They can be combined with other LoG3 or higher control measures that treat vehicular areas to provide a higher level of treatment over a wider area.

Native soils can be amended to provide infiltration capability as well as provide better growing conditions for plant material. These shallow swales will manage a low volume of stormwater and can therefore support a wide range of plant species. The runoff will supplement the need for irrigation and reduce potable water demand.

Components		Suitable Types					
		A	B	C	D	E	F
1	Inlet	🟠	○	○	○		
2	Forebay	○	○	○	○	🟠	○
3	Grade Control	○	○	○	○	🟢	🟢
4	Edge Barrier	🟠	🟠	🟠	🟢	🟠	
5	Subsurface	○	○	○	○		
6	Overflow	○	○	○	○	○	
🟢	Appropriate	🟠	Appropriate w/ conditions		○	Not Applicable	

Side slopes of the swale should be 5:1 or less. If the runoff ratio of tributary area is within 25% of the maximum recommended for the given Level of Green an overflow notch should be added to provide a route for overflow to the curb and gutter.

[RECESSED TREE ZONE]

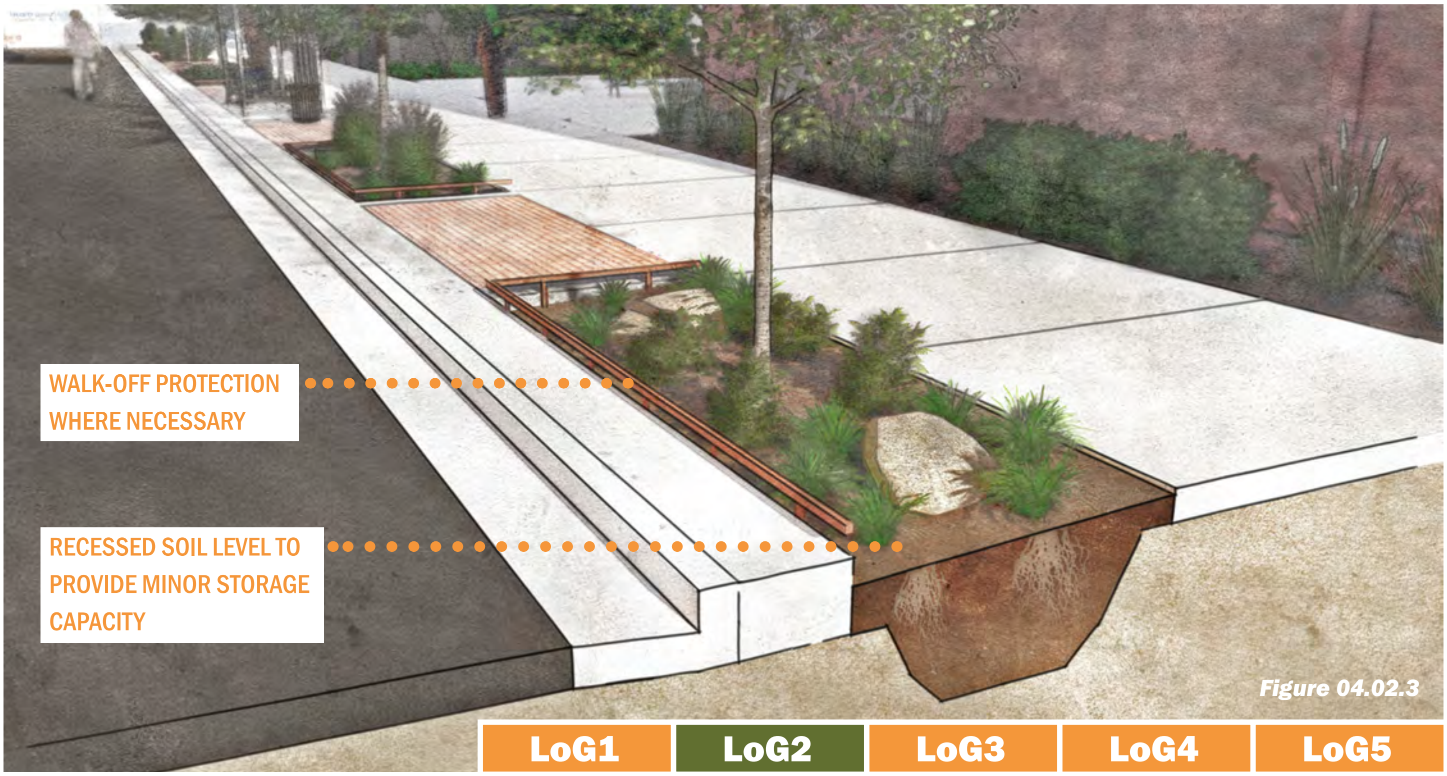


Figure 04.02.3

02.3 - RECESSED TREE ZONE

Similar in function to Tree Canopy (02.1), Structural Soil Cells (02.4), and the Tree Lawn Swale (02.2), the Recessed Tree Zone is intended to provide temporary, shallow stormwater management capacity in amenity zones and tree lawns adjacent to larger pedestrian areas.

The shallow stormwater storage zones manage small volumes of runoff in space constrained areas or when used in combination with other Green Continuum control measures. For example, Pervious Amenity Zones (02.5) and Curb Extensions (02.11) are two SCMs that can be combined with a Recessed Tree Zone to provide a higher level of treatment for larger projects.

The finished surface of soil or media will be recessed from the finished surface of the adjacent sidewalk one to four inches and may need an edge barrier to prevent a tripping hazard. For any drops 2-inches or more, it is recommended to use an edge barrier for walk-off protection.

The soil can be flat for a uniform look below the sidewalk, or sloped so that one edge is flush with the sidewalk and one edge lower, as shown in the above graphic. A flat soil surface can provide more volume if necessary, but a sloped surface can allow for one edge to not require any kind of walk-off protection or edge barrier.

Components		Suitable Types					
		A	B	C	D	E	F
1	Inlet	🟠	○	○	○		
2	Forebay	○	○	○	○	🟠	○
3	Grade Control	🟢	○	○	○	🟢	🟢
4	Edge Barrier	🟠	🟠	🟠	🟢	🟢	
5	Subsurface	○	○	○	🟢		
6	Overflow	○	○	○	○	○	
🟢	Appropriate	🟠	Appropriate w/ conditions	○	Not Applicable		

[STRUCTURAL SOIL CELLS]

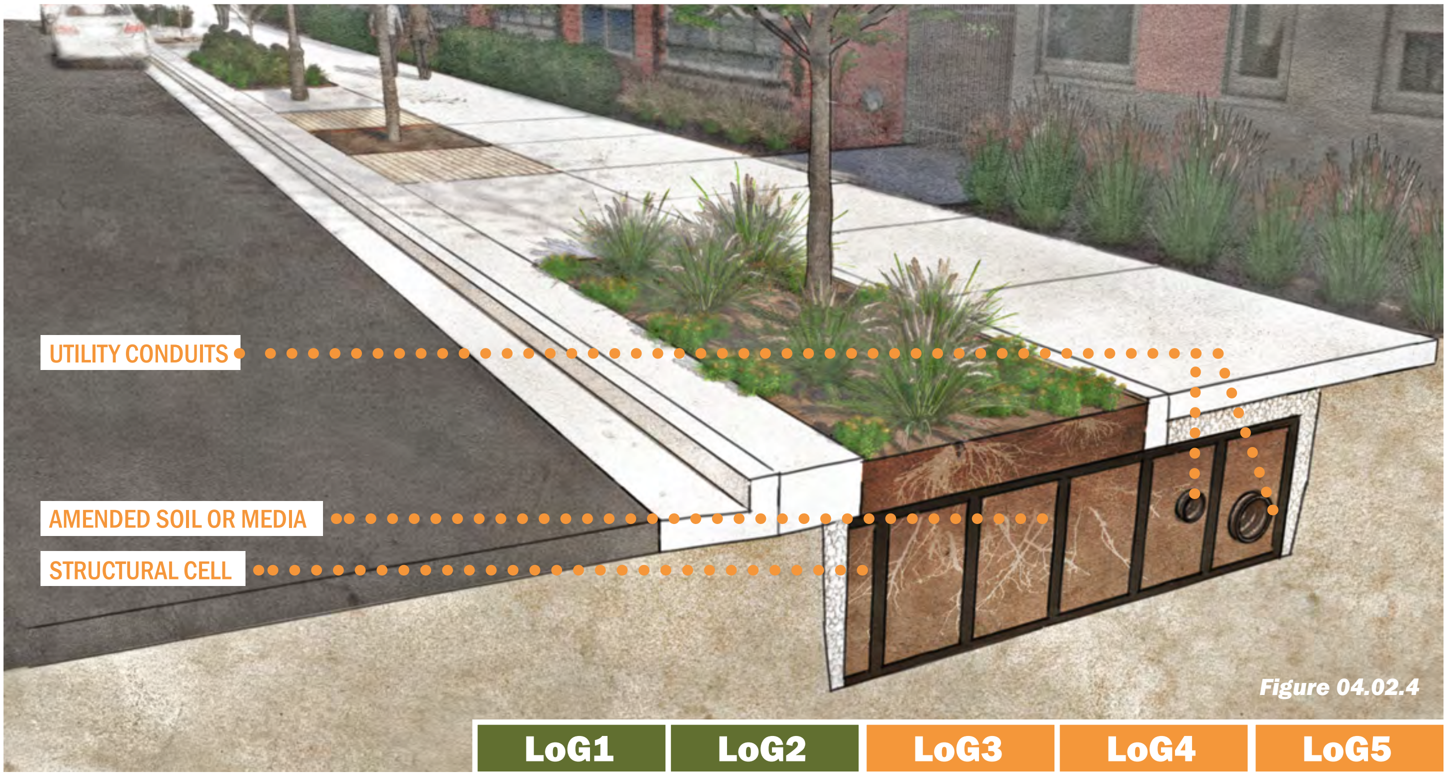


Figure 04.02.4

02.4 - STRUCTURAL SOIL CELLS

As discussed in Tree Canopy (02.1), adequate soil volume is critical to grow healthy trees in dense, urban landscapes, particularly in the dry Steppe climate along the Front Range.

Structural soil cells are engineered systems designed to hold up paving and other walkable surfaces over uncompacted soil volumes to provide ideal growing conditions for tree roots. Structural soil cells can be utilized under amenity and tree lawn zones and extended under pedestrian plazas, bike lanes, and sidewalks to help achieve ideal soil volumes. This allows the imported or amended soil to remain uncompacted so that roots can more easily spread and loosen subgrades. Uncompacted soils allow for easier growth of roots and deeper infiltration by water and air.

While structural cells can be used in any LoG, they are recommended for use on soil volumes in LoG1 and LoG2 where they can accept incidental stormwater runoff from adjacent pedestrian areas but do not require any subsurface infrastructure.

Structural cells also allow for additional space to accommodate stormwater distribution, storage, infiltration, and treatment. When used as LoG3, LoG4, or LoG5 SCMs, structural cells will require additional considerations for use to manage runoff reduction or water quality. *The Ultra Urban Green Infrastructure Guidelines* include details and specifications for the Tree Trench and the critical components necessary for use in these levels.

Components		Suitable Types					
		A	B	C	D	E	F
1	Inlet	🟢	🟢	🟢	🟢		
2	Forebay	🟠	🟠	🟢	🟢	🟠	🟠
3	Grade Control	🟠	🟢	🟢	🟢	🟠	🟠
4	Edge Barrier	🟢	🟢	🟢	○	🟢	
5	Subsurface	🟢	🟠	🟠	○	🟠	
6	Overflow	🟢	🟢	🟢	🟢	🟢	
🟢	Appropriate	🟠	Appropriate w/ conditions	○	Not Applicable		

[PERVIOUS AMENITY ZONE]

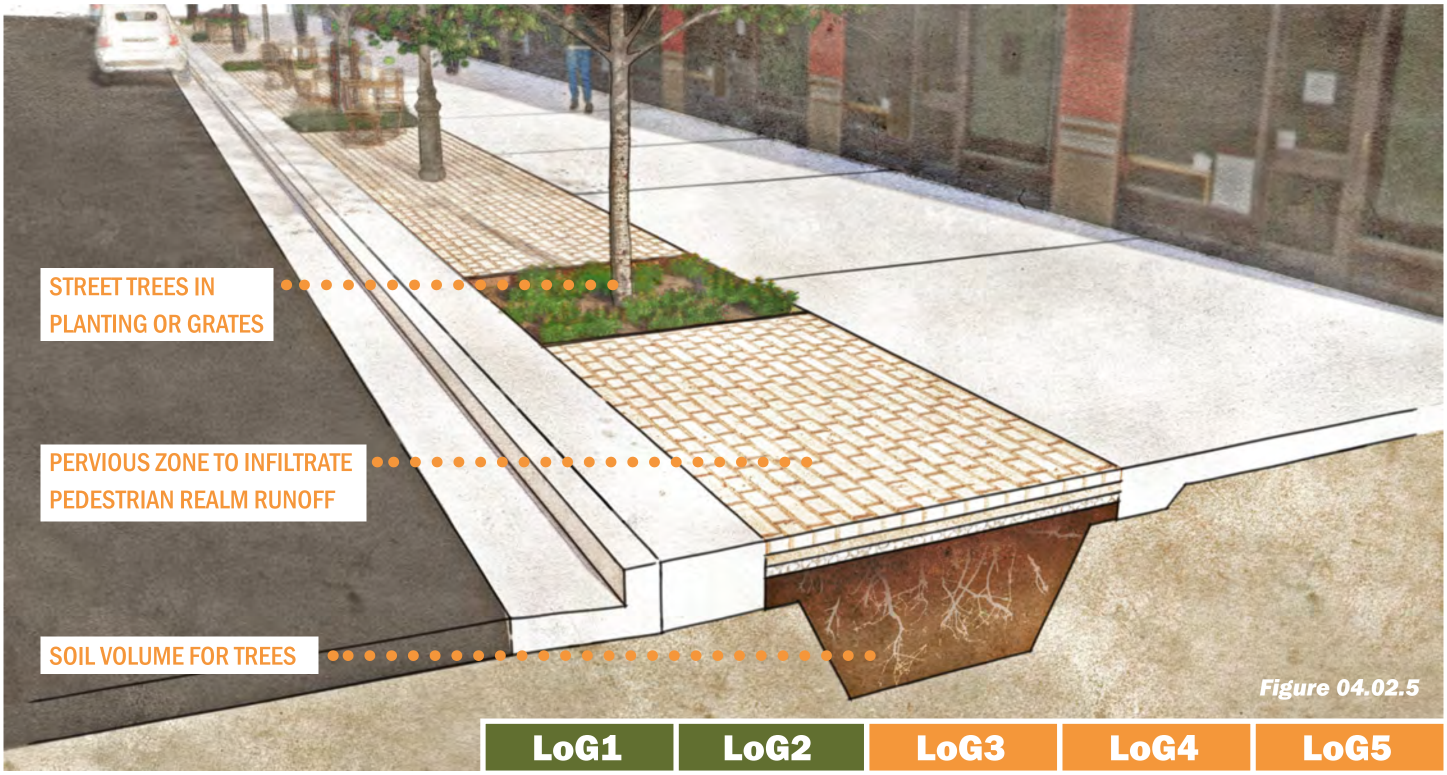


Figure 04.02.5

02.5 - PERVIOUS PAVING (AMENITY ZONE)

Pervious paving allows stormwater to infiltrate directly into the ground to recharge groundwater, be collected in underground storage, or be collected and conveyed to the storm system. In Denver, pervious paving is typically pre-cast concrete pavers or open-cell systems designed to allow infiltration to subgrade.

Pervious paving in the amenity or tree zones, when used in tandem with Tree Canopy and Structural Tree Cell control measures, can fully manage stormwater runoff from sidewalks and plazas to improve water quality and provide significant runoff reduction in dense urban areas. The infiltrating stormwater provides additional water to root systems of trees and vegetation and reduces the amount of supplemental irrigation.

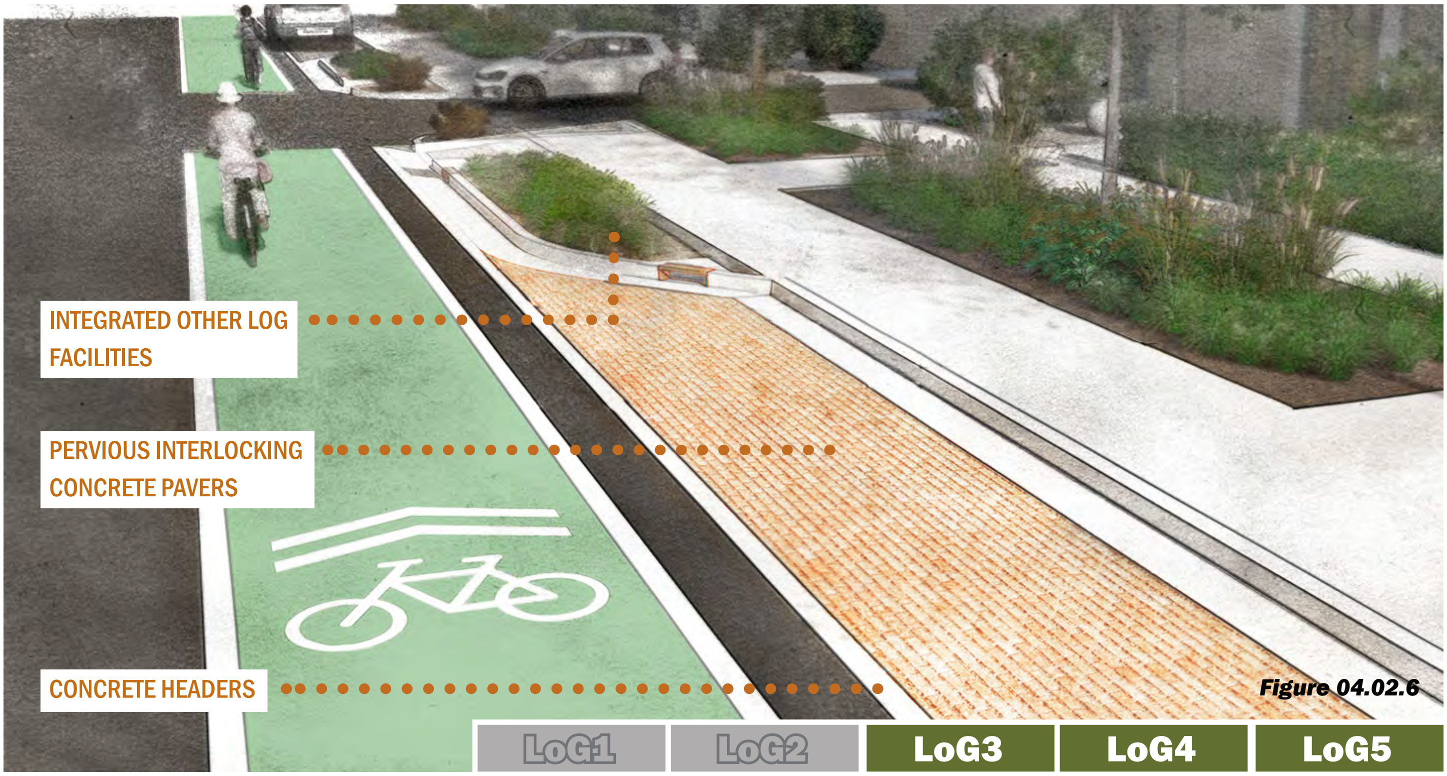
Pervious amenity zones work well together with vegetated zones around trees to create a fully pervious amenity zone. Because stormwater can directly infiltrate and provide water to tree roots, the standard 5x15 required area around street trees can be partially filled with pervious paving. When utilized in a streetscape adjacent to commercial or mixed use buildings, the additional hardscape allows for more flexible use of the public realm.

Components		Suitable Types					
		A	B	C	D	E	F
1	Inlet	○	○	○	○		
2	Forebay	○	○	○	○	○	🟢
3	Grade Control	🟠	🟠	🟠	🟠	○	○
4	Edge Barrier	○	○	🟠	○	🟠	
5	Subsurface	🟢	🟢	🟢	🟠		
6	Overflow	○	○	○	○	🟢	
🟢	Appropriate	🟠	Appropriate w/ conditions	○	Not Applicable		

When constraining the open soil areas around trees with pervious paving it's important to include a methodology for removing or adjusting the paving around the trees as they grow to prevent girdling of the trunk. Some other important considerations are:

- Identify the supportive base for the pervious pavers and determine if it can be installed without overcompacting the soil for the tree roots.
- Choose paving systems that allow for removal or adjustment to accommodate other critical amenity zone elements like lighting, benches, fire hydrants, etc.

[PERVIOUS PARKING]


INTEGRATED OTHER LOG FACILITIES

PERVIOUS INTERLOCKING CONCRETE PAVERS

CONCRETE HEADERS

Figure 04.02.6

02.6 - PERVIOUS PAVING (PARKING ZONE)

Pervious paving is utilized primarily in pedestrian areas and in low volume vehicular areas, such as parking lots and parking lanes. See Pervious Amenity Zones (02.5) for more information on use in pedestrian areas. Pervious paving comes in a variety of different materials including concrete, asphalt, concrete pavers, and cast-in-place (CIP) open-celled concrete.

Pervious concrete and asphalt have been tested locally but Denver's cold-weather climate with extreme freeze and thaw cycles have shown them to be problematic. Pervious concrete pavers and CIP open-celled concrete with vegetation have proven to be the most resilient, particularly in low-volume vehicular uses.

Pervious paving, used in the parking zone, can manage water quality and runoff reduction for an area up to five times larger (5:1 run-on ratio) than the pervious area. Pavers have many benefits including flexible patterns, colors, and installation processes. Pervious paving can be installed over a variety of sand filter and storage rock configurations to achieve a wide range of water quality and runoff reduction goals. Depending on which LoG a project is utilizing, the underground requirements for setting sand, rock base, storage, underdrains, and protection liners may vary depending on subsurface conditions, nearby utilities, and adjacent land uses.

Long term maintenance is an important consideration as the removal of sediment and trash from the voids with regular vacuuming is required. Paving in vehicular areas may require a much higher level of maintenance than pedestrian zones due to sediment and pollution loading.

Components		Suitable Types					
		A	B	C	D	E	F
1	Inlet	🟠	○	○	○		
2	Forebay	○	○	○	○	○	🟢
3	Grade Control	🟠	🟠	🟠	🟠	○	○
4	Edge Barrier	○	○	🟠	○	🟠	
5	Subsurface	🟢	🟢	🟢	🟠		
6	Overflow	○	○	○	🟠	🟢	
🟢	Appropriate	🟠	Appropriate w/ conditions	○	Not Applicable		

[SHALLOW SWALE]

Figure 04.02.7

LoG1 | **LoG2** | **LoG3** | **LoG4** | **LoG5**

02.7 - SHALLOW FLOW-THROUGH SWALE

Similar in goals and function to Recessed Tree Zone (02.3) and Tree Lawn Swale (02.2), the Shallow Flow-through Swale is a recessed landscape set at or just below the adjacent curb and gutter line allowing stormwater to enter the stormwater control measure (SCM) from both pedestrian and vehicular impervious areas. Sloped edges and a partial flat-bottom allow the control measure to provide minimal storage and still blend into residential, light commercial, and industrial areas.

The shallow flow-through swale is an ideal LoG3 facility and is intended to be flexible in shape and length, relatively inexpensive to build and simple to design and install. This control measure is not intended to have significant volumetric storage but can be combined with other LoG4 and LoG5 SCMs to reduce the overall size of control measures intended to provide WQCV. Native in-situ soils should be amended to provide minor infiltration ability and better growing conditions for low-water native and adapted landscapes.

Some of the key benefits of this SCM, beyond simplicity and lower costs, is the ability to capture sediment and trash while providing some minimal storm runoff reduction.

Components		Suitable Types					
		A	B	C	D	E	F
1	Inlet	🟢	🟢	🟢	○		
2	Forebay	🟢	🟢	○	○	🟠	🟢
3	Grade Control	🟢	🟠	🟠	○	🟢	🟢
4	Edge Barrier	🟠	🟠	🟠	🟠	🟢	
5	Subsurface	🟠	🟢	🟠	○		
6	Overflow	🟢	🟠	🟢	○	○	
🟢	Appropriate	🟠	Appropriate w/ conditions		○	Not Applicable	

Because the Shallow Swale control measure is accepting runoff from a vehicular zone, a forebay should be included to capture sediment and trash.

Inlet and outlets should be designed to ensure that there is no standing water within the overall facility. Minor ponding may be necessary due to grade and street slope, but it should be kept to a minimum.

[RAIN GARDEN]

Figure 04.02.8

02.8 - RAIN GARDEN

Rain Gardens are open-bottomed bioretention stormwater control measures (SCM) intended to capture and infiltrate stormwater to subgrade, much like Infiltration Planters (02.9). Rain gardens are ideal for use where space is less constrained. They can accept runoff from pedestrian and vehicular areas and work well in curbless zones, parking lots, traffic triangles, or oddly shaped urban areas. Rain gardens can utilize a larger footprint, sloped edges, and shallow storage to allow flexibility in shape and size so that they may fit more aesthetically into the landscape.

The opportunity for flexible design also requires special consideration of the components necessary to allow rain gardens to function properly. Inlets and forebays should be included to manage runoff from vehicular areas whereas scuppers in an edge barrier should be included to manage sheet flows from adjacent pedestrian zones. Grade control and edge barriers should be used when grade drops more than 2-inches from any adjacent impervious areas.

Rain Gardens are generally infiltration-only control measures in LoG3 and LoG4 and will not typically have subsurface drainage. When Rain Gardens are utilized as an LoG5 SCM they can manage full WQCV volumes, but should be designed to include underdrains and overflow control structures.

Components		Suitable Types					
		A	B	C	D	E	F
1	Inlet	🟢	🟢	🟢	🟢		
2	Forebay	🟢	🟢	🟠	🟠	🟠	🟠
3	Grade Control	🟢	🟢	🟠	○	🟢	🟢
4	Edge Barrier	🟢	🟢	🟢	🟠	🟢	
5	Subsurface	🟠	🟢	🟠	○		
6	Overflow	🟢	🟢	🟠	🟠	🟠	
🟢	Appropriate	🟠	Appropriate w/ conditions	○	Not Applicable		

Soil and vegetation may vary considerably depending on intended function. For example, a Rain Garden intended as an LoG3 flow-through SCM will require vegetation that can withstand shallow standing water and frequently wet roots in amended soils, whereas in an LoG5 volume SCM will require vegetation that can withstand deep standing water for longer periods as well as long periods of drought in a fast-draining media.

[INFILTRATION PLANTER]

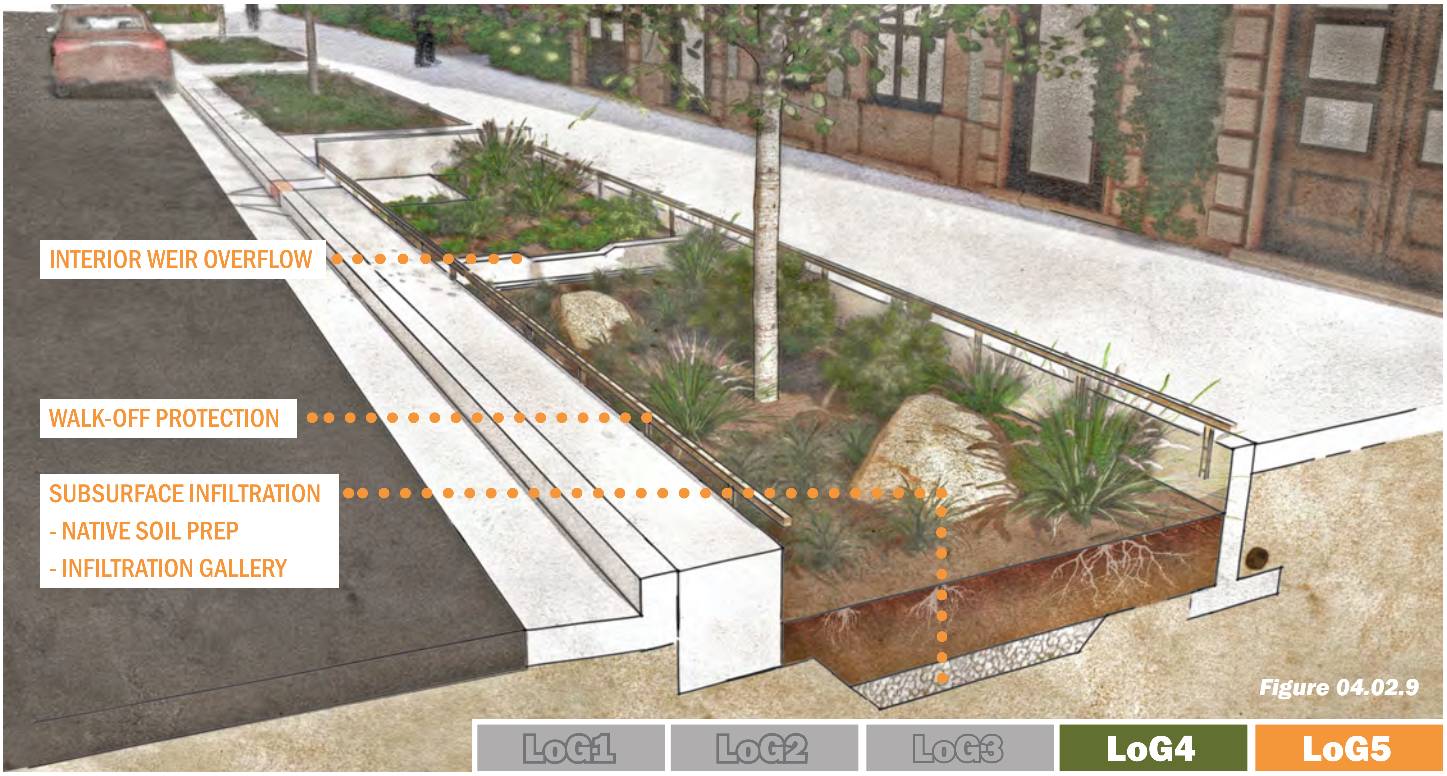


Figure 04.02.9

02.9 - INFILTRATION PLANTER

Infiltration planters are open-bottomed bioretention stormwater control measures (SCM) intended to capture and infiltrate stormwater to the subgrade. There are two general types of infiltration planters; full and partial infiltration. Full infiltration planters do not have subsurface drainage, but may include rock infiltration galleries to provide additional volumetric storage below grade rather than above. Partial infiltration planters are open bottomed but may include limited subsurface drainage routed directly to the storm sewer system. Volumetric storage of stormwater is not the primary objective, therefore Infiltration Planters are ideal as LoG4 SCMs to provide runoff reduction as well as water quality.

Infiltration planters as LoG4 SCMs have shallow surface storage and may blend in visually in urban areas more easily than deeper LoG5 control measures. Infiltration Planters will often have vertical walls to minimize footprints, but can also be designed with slopes on one or more sides to reduce the costs of walls as well as blend in aesthetically.

Infiltration planters require an inlet, an outlet or overflow, forebay components, and may also require edge barriers and grade control depending on context. Overflow components typically direct stormwater back into the curb and gutter (similar to inlets) or over interior weir walls to create multi-celled facilities that provide additional area for infiltration.

Components		Suitable Types					
		A	B	C	D	E	F
1	Inlet	🟢	🟢	🟢	🟢		
2	Forebay	○	○	🟢	🟢	○	🟠
3	Grade Control	🟠	🟢	🟢	🟢	🟠	🟠
4	Edge Barrier	🟢	🟢	🟢	○	🟢	
5	Subsurface	🟠	🟢	🟢	○		
6	Overflow	🟢	🟢	🟢	🟠	🟠	
🟢	Appropriate	🟠	Appropriate w/ conditions		○	Not Applicable	

A green infrastructure planting media blend (see section 3 this chapter) should be used at 18-36-inches of depth. If additional temporary storage volume capacity is needed to achieve WQCV volumes, a drain rock or cobble storage volume can be included beneath the media as long as it does not interfere with tree roots ability to access native subgrade.

[STORMWATER PLANTER]

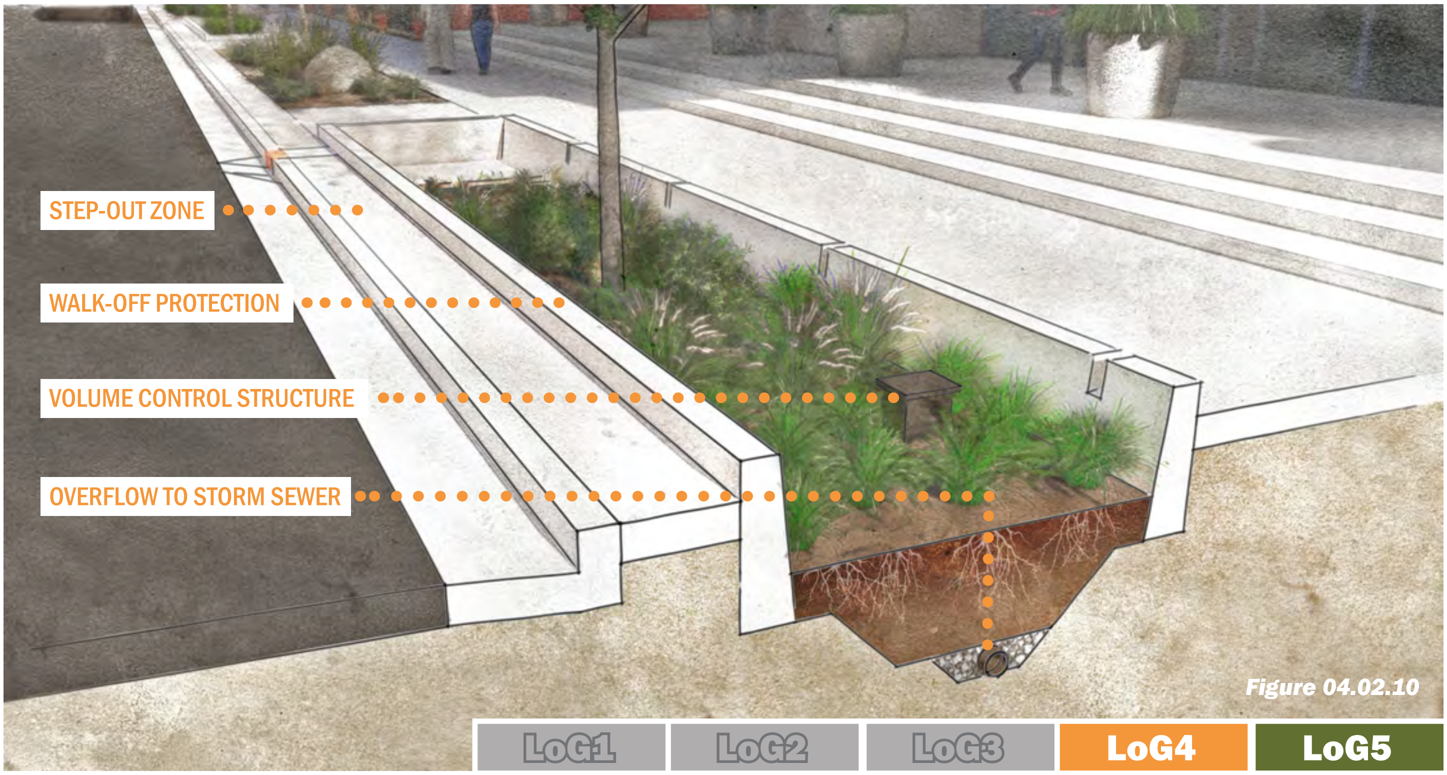


Figure 04.02.10

02.10 - STREETSIDE STORMWATER PLANTER

Streetside Stormwater Planters are bioretention stormwater control measures (SCM) typically located behind the curb in the tree lawn or amenity zone with the right-of-way. Streetside stormwater planters can be utilized in different Levels of Green as pass-through (LoG3), infiltrating planters (LoG4), and water quality and runoff reduction facilities (LoG5) intended to meet regulatory requirements. They may be open-bottomed to maximize infiltration, partially lined to protect subsurface utilities or other features, or fully-lined to prevent infiltration to protect features or prevent groundwater intrusion.

Treatment processes include filtration, absorption and adsorption, and plant uptake. A variety of vegetation can be established in streetside stormwater planters including grasses, perennials, shrubs, and a limited number of trees.

Streetside stormwater planters are ideal in dense, urban situations where maximizing the amount of stormwater storage and infiltration is necessary to meet regulatory requirements or other project goals. By maximizing storage volumes, a typical project may be able to utilize fewer facilities or push them to the corners as curb extensions that can be combined with other desirable multi-beneficial features (see Curb Extension Planter, 02.11).

Components		Suitable Types					
		A	B	C	D	E	F
1	Inlet	🟢	🟢	🟢	🟢		
2	Forebay	🟠	🟠	🟢	🟢	🟠	🟠
3	Grade Control	🟠	🟢	🟢	🟢	🟠	🟠
4	Edge Barrier	🟢	🟢	🟢	○	🟢	
5	Subsurface	🟢	🟠	🟠	○	🟠	
6	Overflow	🟢	🟢	🟢	🟢	🟢	
🟢	Appropriate	🟠	Appropriate w/ conditions		○	Not Applicable	

Stormwater typically enters through a curb inlet and onto a forebay sediment pad from the vehicular zone, or through curb scuppers in the edge barrier/grade control from the pedestrian zone. Overflow is through a curb cut or notch, a control structure in the facility, or over a weir structure to another cell.

A green infrastructure media blend is required at 18-36-inches of depth to maximize infiltration capacity and storage volume to meet regulatory requirements for WQCV.

[CURB EXTENSION]

Figure 04.02.11

02.11 - CURB EXTENSION PLANTER

The Curb Extension Planter is similar in function to the Streetside Stormwater Planter (02.10) but is located at an intersection in combination with a bulb-out or curb extension designed for transportation or other drainage reasons. A Curb Extension Planter can function as a flow-through (LoG3) landscape, an infiltration facility (LoG4), and as a water quality and runoff reduction facilities to meet regulatory requirements (LoG5).

Curb extensions are often more efficient and compact than Streetside Stormwater Planters. Square facilities are more efficient than long, linear facilities by distributing stormwater over a larger area more quickly and allowing inlets and control structures to function better. Curb extensions also narrow streets which can improve safety by reducing crossing distance and providing speed calming to help protect pedestrians, bicyclists, and parked vehicles.

By locating the stormwater planter function at a corner the footprint of a control measure can be configured in a variety of ways to include parking zones, amenity zones, and to share the space at a corner when the curb is modified to meet other transportation goals.

Components		Suitable Types					
		A	B	C	D	E	F
1	Inlet	🟢	🟢	🟢	🟠		
2	Forebay	○	○	🟢	🟢	○	🟠
3	Grade Control	🟠	🟢	🟢	🟢	🟠	🟠
4	Edge Barrier	🟢	🟢	🟢	○	🟢	
5	Subsurface	🟢	🟠	🟠	○		
6	Overflow	🟢	🟢	🟢	🟢	🟢	
🟢	Appropriate	🟠	Appropriate w/ conditions		○	Not Applicable	

This design flexibility allows for SCMs with flat bottoms and vertical walls or a range of slopes that allow for differing approaches for types of media and plant palettes. For example, a sloped edge will allow for upland trees and understory plantings that may not survive in the lower inundation zones.

Curb extensions typically will impact the flow line of the curb and gutter and will direct all stormwater into the SCM, unlike a streetside stormwater planter. Inlets and forebays should be larger to accommodate more flows and overflows more carefully designed to prevent ponding water conditions in the street.

03 - STORMWATER MANAGEMENT COMPONENTS

All of the stormwater control measures (SCM) selected to meet a Level of Green are made up a set of components: individual elements that control an SCMs form and function. One example of a component is the Inlet (See 03.1, this chapter), the location where stormwater enters the SCM. The same type of inlet (e.g., a curb cut) can be used on different SCMs and different Levels of Green, if appropriate. Additionally, components can be chosen specifically to change the SCMs Level of Green. One example of this is an SCM with an underdrain may be an LoG5, while the same without an underdrain may be an LoG4.

This section contains a list of components, design alternatives for each component, and guidance on selecting the best alternative. Selection should be based on the desired Level(s) of Green for the SCM or project, adjacent land use, site context, and aesthetics. The components listed first (vegetation, media, irrigation, and subsurface) do not have specific alternatives listed, only general guidance that is useful for design. The components listed second (inlets, forebays, grade control, edge barrier, underdrain, and overflow) have clear alternatives with examples.

Components are presented this way to inspire creativity and to open the design toolbox, resulting in more functional, better looking, and diverse SCMs.

SUBGRADE/MEDIA TRANSITION ZONE

The subgrade is the native soil directly below the stormwater control measure. It is cost prohibitive to replace this soil layer but steps can be taken to prepare the subgrade to improve performance of the facility after construction.

The subgrade should be scarified to a minimum depth of 6 inches prior to placing amended soil or media into the facility. After scarifying, 2-3 inches of media should be placed and mixed into the scarified subgrade to create a 9-inch deep transition zone mix of native subgrade and media. After scarification and mixing, the remaining media can then be placed to final depth in lifts to reduce the potential for compaction of subgrade and media.

This media transition zone step will remediate any compaction that occurred due to construction, help promote deeper infiltration, and make it easier for plant roots to extend into the subgrade to access water and nutrients.

SOIL & MEDIA

The media in any landscape is an important consideration, and all disturbed landscapes should include planning for evaluating and amending native soils. With all LoGs the media zone will need to be evaluated for its capacity to temporary store, infiltrate, treat, and release stormwater both for water quality and to provide plant material with water and nutrients.

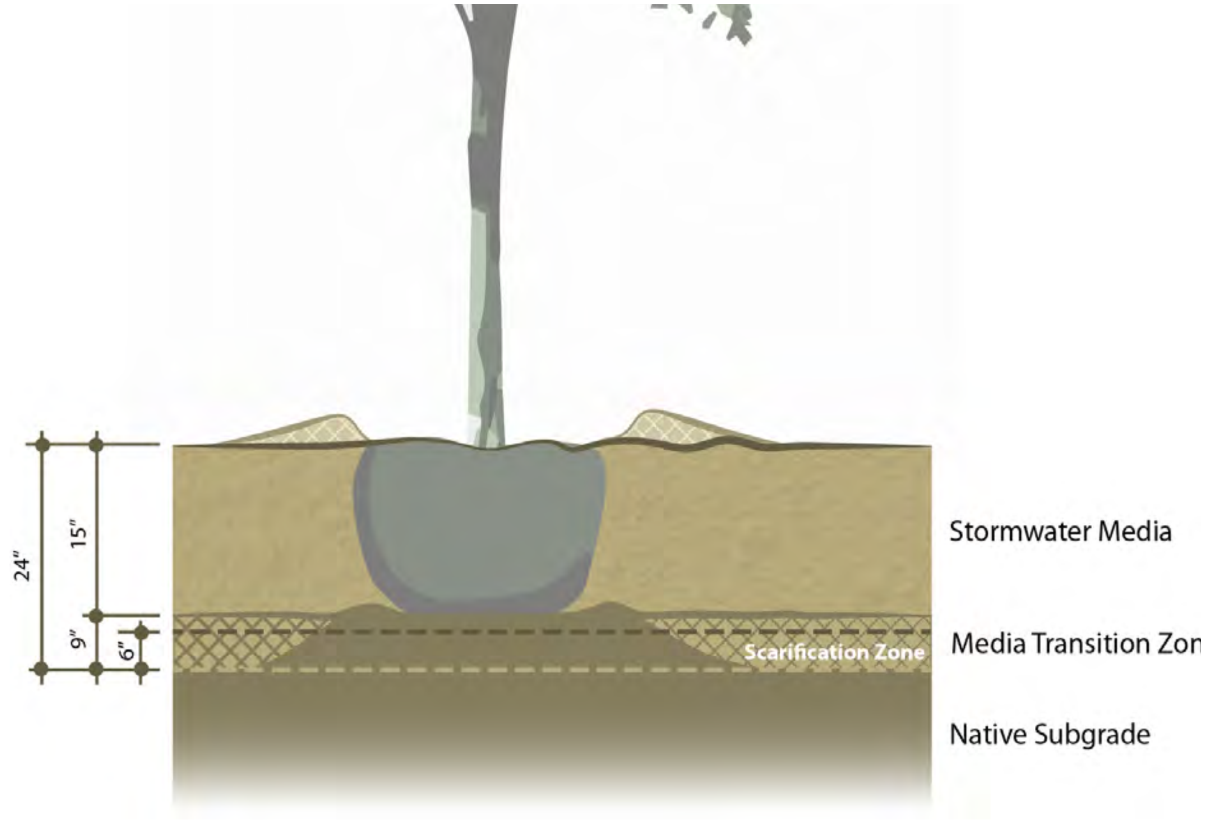


Figure 04.03.1: Media Transition Zone

Depending on the performance considerations for the landscape, many native soils may be amended in place for infiltration and nutrients, such as in LoG1 landscapes. In other more engineered landscapes, such as in LoG2 and some LoG3 facilities, an in-situ blending of bioretention media and native soils may be adequate to meet performance needs. Denver's Own EcoGro, a brand of compost produced by Denver's municipal composting program, should be considered when amending or importing soils specifically for added organic matter, nutrients, and moisture retention as on LoG1 and LoG2 projects. Using this compost on projects both supports plant growth as well as other city sustainability objectives. Finally, in more highly engineered facilities utilized in LoG4 and LoG5, a specifically engineered media designed to maximize storage and infiltration may be needed to meet key stormwater performance needs.

It may be appropriate to add a surface treatment on top of the growing media. Wood mulch can help retain moisture in facilities that do not pond or convey runoff, such as LoG1 and some LoG2 facilities. However, mulch should not be used in LoG3, LoG4, or LoG 5 facilities as it floats and migrates during inundation, except in upland areas outside of inundation zones. Rock mulch should be avoided as it can lead to solar reflection and higher temperatures that are not conducive for vegetation growth and contribute to urban heat island.

Facilities that convey runoff at higher velocities, such as LoG3 facilities and some LoG4-5 facilities with significant grade (>1%), may require gravel, river rock, or cobble in some locations to armor the growing media from erosion. Designers will need to consider slope, flow velocity, and run-on ratios when selecting the armoring material.

VEGETATION

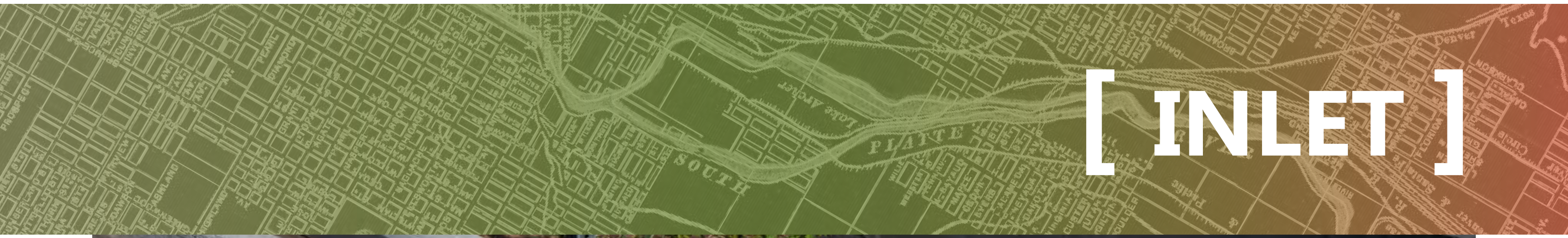
The type of vegetation used in each Level of Green is critical to both the functional aspects of SCMs as well as the aesthetic considerations in the urban environment. The designer should choose plants that take site context, water movement through the SCM, potential pollutant loading, intended hydroperiod, and primary function of the plant material in each control measure into account when developing a plant palette. The soil/media and subgrade also have a direct influence on how plants should be chosen. A list of understory plants that are appropriate for the growing conditions found in each Level of Green is provided in Appendix 1. A full list of tree species appropriate for the right-of-way, including trees appropriate for SCMs, can be found on The Office of the City Forester's website. A subsection of this list, also organized by each Level of Green, is provided in Appendix 1.

IRRIGATION

All SCMs should include an irrigation system to support the vegetation that is vital to performance. Irrigation plans must include a schedule for all zones for initial establishment; 12 to 36 months from initial planting depending on contracting of the original installation. In addition, there must be a zone schedule for after establishment that reflects the long-term goals for plant health and reduced water usage. Planting the recommended species should require a fraction of the establishment irrigation rates of typical, ornamental landscapes.

Overhead spray irrigation heads are preferred because breaks and failures can be observed more easily, preventing plant material from being impacted. Drip irrigation can only be used in circumstances where spray is not a practical solution (i.e., narrow planters). Points of connection, master valves, zone valves, quick couplers, and other devices intended to be in valve boxes should be located outside of stormwater facility. If these irrigation components must be located within the facility, site as far from inlet as possible.

Figure 04.03.2: Irrigation Component



[INLET]

Figure 04.03.3

03.1 - INLET

For Levels of Green where stormwater runoff is collected from both pedestrian and vehicular areas, the configuration of the inlet is a critical component.

Where stormwater is entering an SCM from vehicular portions of the right-of-way, an inlet shall be located at the upstream end of the planter and be sized to convey the tributary water quality storm flow assuming an appropriate amount of debris blockage. The opening length of inlet required will vary depending on flow rate and longitudinal slope. Figure 1, Pg 5 in *Denver's Ultra-Urban Green Infrastructure Guidelines*, or the *MHFD Criteria Manual - Volume 1,* can be used to determine the length of inlet required for a given upstream area (assumed to be fully impervious). The UUGIG sizing includes a 10% debris factor in the calculations.

The inlet is typically designed to function in concert with a forebay or pretreatment filter, which is intended to capture the majority of litter, debris, and sediment entering the planter.

INLET TYPE		LoG 1	LoG 2	LoG 3	LoG 4	LoG 5
A	Curb Cut	🟠	🟠	🟢	🟢	🟢
B	Pre-fab Metal Curb Cap	○	○	🟢	🟢	🟢
C	Pre-fab Metal Opening	○	○	🟢	🟢	🟢
D	Cast Iron Chase	○	○	🟢	🟢	🟢

🟢 Appropriate | 🟠 Appropriate w/ conditions | ○ Not Applicable

KEY INLET DESIGN CONSIDERATIONS:

- If the inlet is along a parking lane, a vehicular lane, or a route that is intended be snow plowed, a curb cut wheel protection is highly recommended.
- Where the inlet/chase crosses a pedestrian zone or bike lane, the cover and wheel protection must meet all applicable ADA and H-20 loading requirements.
- Where pre-fabricated wheel protection is utilized, a minimum of 6-inches clearance shall be maintained.
- The gutter line shall be depressed 2-inches at all inlets to redirect water into inlets unless doing so causes slopes to exceed applicable standards.
- The downstream elevation of the inlet is typically the feature that controls the water surface elevation (WSE).

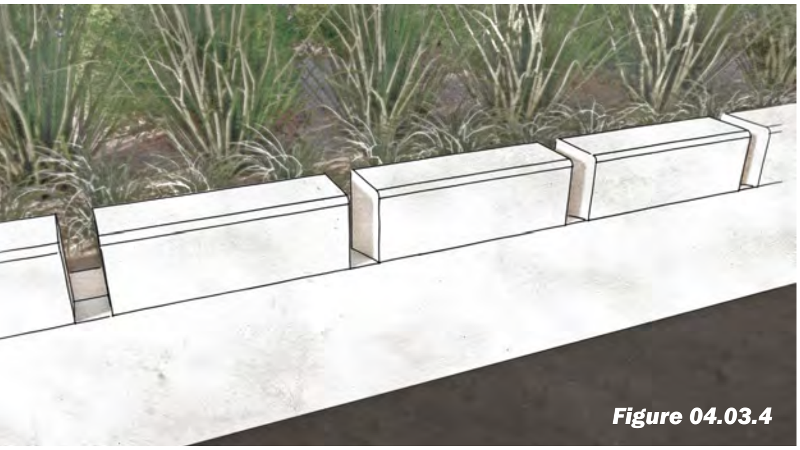


Figure 04.03.4

TYPE A - CURB CUT

This approach is appropriate at the edge of a parking lot, along a bike lane, or along pedestrian areas such as plazas and sidewalks. The cut will be sized according to tributary size and design flow rates and may require a narrow forebay.

This type of inlet structure is not intended for use along a street or sidewalks designated snow plow routes.

See Type E Forebay for information related to forebay sediment pads on Type A curb cuts.

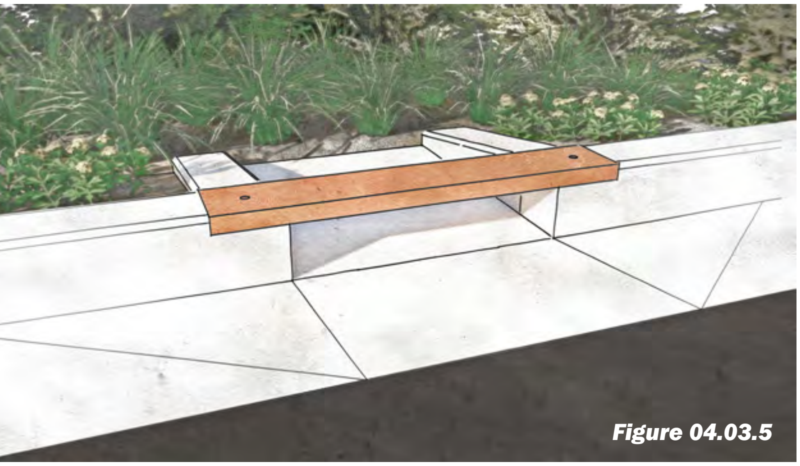


Figure 04.03.5

TYPE B - PRE-FAB CURB CAP

Wheel and snow plow protection should be used on any curb cut adjacent to vehicular lanes, parking, or on snow plow routes. This prefabricated metal opening continues the elevation of the top of the curb while also creating an entry point below at the flowline level.

This metal curb cap is ideal for retrofit curb cuts or where there are aesthetic reasons to not utilize the Type C - Pre-fab Opening inlet.

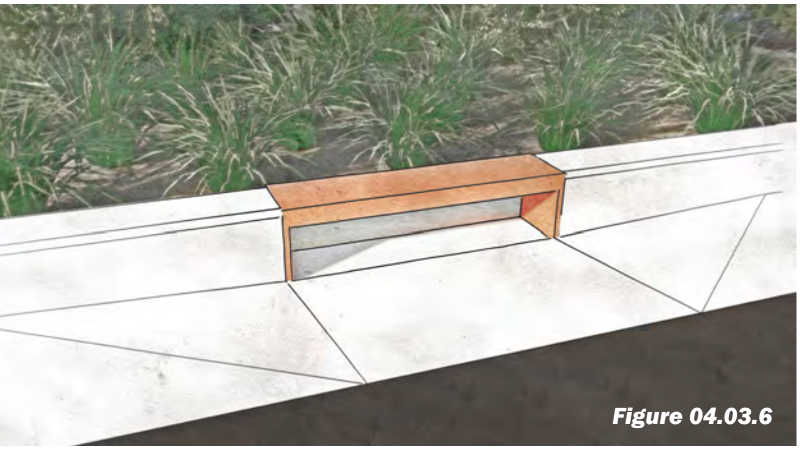


Figure 04.03.6

TYPE C - PRE-FAB OPENING

Also know as a “staple”, this pre-fabricated inlet opening is very similar to Type B, but can be incorporated in the forms for a curb.

Both Type B and Type C allow flow from the gutter to enter into the facility and onto a forebay. The gutterline should be depressed 2-inches to help direct flows into the control measure.

Pre-fab openings may also be in alternative materials like pre-cast concrete.

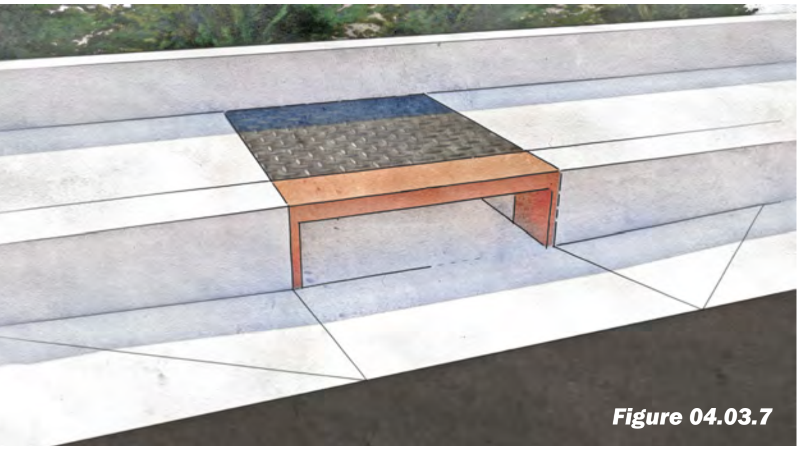


Figure 04.03.7

TYPE D - CAST IRON CHASE & GRATE

This cast iron chase and grate is utilized when flows must pass through a distance greater than a standard curb width. Examples would be crossing a step-out zone or a bike lane. It uses a formed depression in a standard curb to create an opening at the flow line level which allows for right-of-way flows to enter the SCM.

This type of inlet will typically interface with a pre-fab opening and a forebay inside the control measure.

[FOREBAY]

Figure 04.03.8

03.2 - FOREBAY

Forebays are located downstream of an inlet and are designed to collect sediment and debris prior to entering the vegetated area. The size of the forebay will vary based on tributary area and anticipated sediment loading based on factors like adjacent land use and street typology. Forebays should be aesthetically incorporated into the planter, be free-draining, and should not retain or pond stormwater.

Forebays may also be designed to dissipate energy where stormwater enters the planter bed. They should typically be constructed of solid surfacing such as concrete but may incorporate some infiltration capacity using pervious pavers or open-cell paving. Forebays should be considered where fall heights into depressed basins become large enough to create erosion or if vegetation is not anticipated to resist erosion sufficiently. Sediment containment lips can be incorporated on the downstream end of the forebay to control sediment migration but must include full-depth drainage slots to allow low flows to enter the vegetated zones.

FOREBAY TYPE		LoG 1	LoG 2	LoG 3	LoG 4	LoG 5
A	Small Pad	🟠	🟠	🟢	🟢	🟠
B	Small Pad with Lip	○	○	🟢	🟢	🟠
C	Full-width Pad	○	○	🟠	🟢	🟢
D	Full-width Pad with Lip	○	○	🟠	🟢	🟢
E	Linear Level Spreader	🟠	🟠	🟠	🟢	🟢
F	Open Cell Pervious	○	○	🟠	🟢	🟢

🟢 Appropriate 🟠 Appropriate w/ conditions ○ Not Applicable

A minimum of 1-2” of grade change should be included between the invert of the inlet and the surface of the forebay, as well as another 1-2” of grade change between the surface of the forebay and the media. This will allow water to flow into and out of the forebay even when there is significant trash or sediment accumulation.

Maintenance will consist of routine shoveling and disposal of the accumulated sediment and trash.

Figure 04.03.9

TYPE A - SMALL PAD

For smaller tributary areas, or low anticipated sediment loading, a smaller forebay pad may be desirable. The pad should be installed over a compacted gravel base and tied into any adjacent walls or curbs with dowels to help prevent settling.

A small pad may also be used in swale or hybrid facilities due to space.

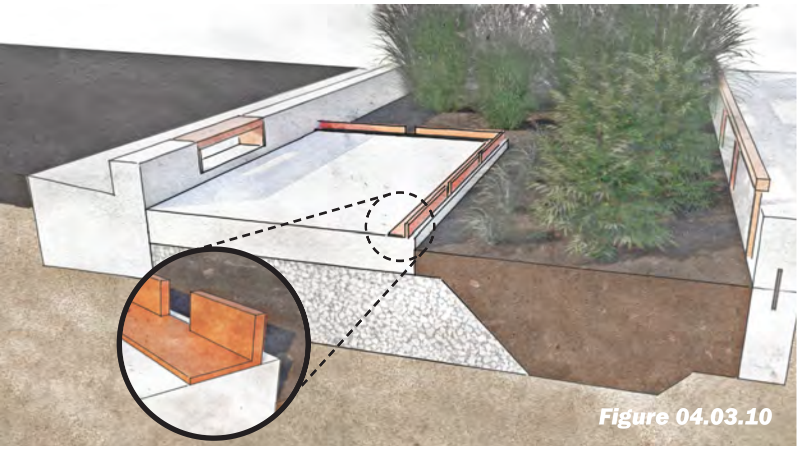


Figure 04.03.10

TYPE B - SMALL PAD WITH LIP

A sediment control lip incorporated in the forebay can help contain sediment on the pad for later removal. The lip could be a top or face mounted steel shape or a concrete lip cast into the pad. At least two regularly spaced gaps must be incorporated in the lip to allow low flows to enter the vegetated part of the facility and prevent standing water.

The top of the lip should be a minimum of 1/2-inch below the water surface elevation (WSE) and not impound water when the pad is full of sediment.

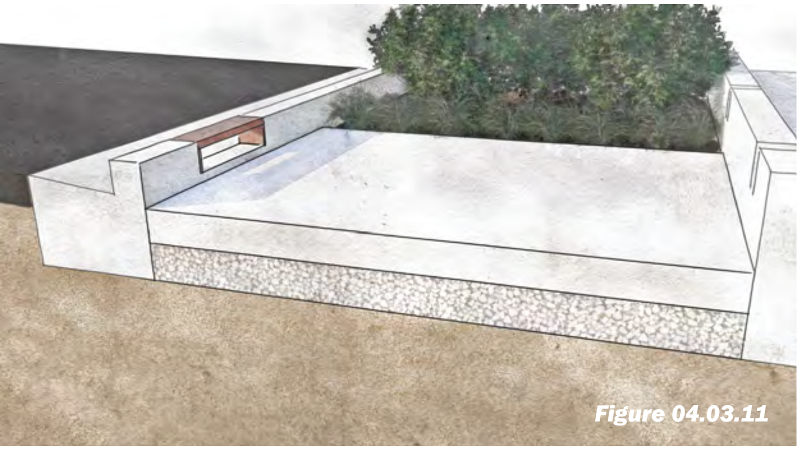


Figure 04.03.11

TYPE C - FULL-WIDTH PAD

Larger tributary areas, or areas with high sediment load, may require a larger forebay pad. Flat-bottom, higher capacity planters that require four walls may also utilize the full-width forebay for both sediment control and aesthetic reasons.

If the choice to use a full-width pad is based on aesethetic or constructability reasons, and not sediement loading, then limit the pad as much a possible to reduce concrete usage.

Figure 04.03.12

TYPE D- FULL-WIDTH PAD WITH LIP

Similar to Type B Forebay, a full-width pad may benefit from a integarated or added lip to contain sediment. At least two full-depth drainage gaps must be included to allow for low-flow drainage of the pad and to prevent standing water.

The top of the lip should be a minimum of 1/2-inch below the water surface elevation (WSE) and not impound water when the pad is full of sediment.

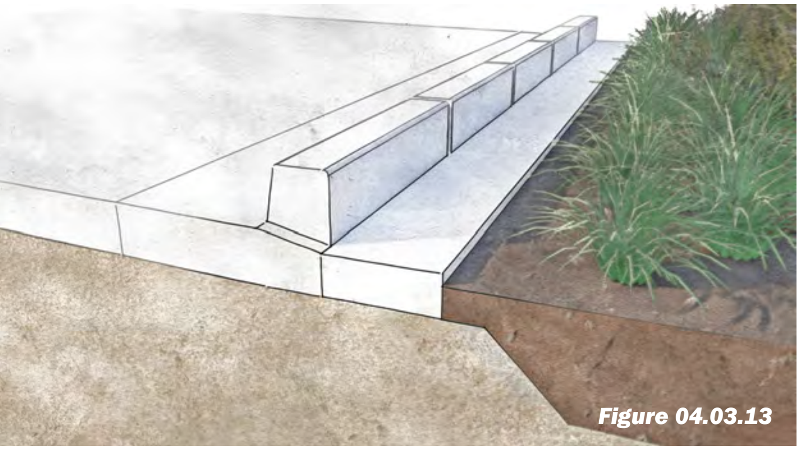


Figure 04.03.13

TYPE E - LINEAR LEVEL SPREADER

Type A Curb Cuts may require sediment pads to help control sediment on linear control measures. These pads are typically narrow (8-12 inches) in long, linear SCMs.

A lip may be incorporated as long as there is enough clearance for a shovel to remove sediment between the curb and lip.

Figure 04.03.14

TYPE F - OPEN-CELL PERVIOUS

In some applications, such as an infiltration only facility, it may be necessary to maximize infiltration areas. An open-cell pervious sediment pad may be used to increase pervoius areas.

Sediment removal may be partially achieved with shovels, but if the pad is vaccumed to remove sediment it may require refreshing of gravel in the cells to improve infiltration capacity.

[GRADE CONTROL]

Figure 04.03.15

03.3 - GRADE CONTROL

Walls surrounding control measures are often needed to contain the media, decrease the potential for saturation of the adjacent soils and facilitate constructability and maintenance of stormwater control measures. Walls are recommended to be built out of either cast in place or pre-cast concrete and can be colored, stained, or stamped. Walls may also be constructed of other durable materials if they are capable of occasional inundation lasting up to 12 hours which creates situated conditions in the media.

Where possible, walls should be minimized to control costs and reduce environmental impacts associated with concrete production. If full depth walls are utilized in a control measure along an arterial road or roads without parking or bike lanes, additional considerations should be given to structural stability particularly in retrofit conditions where existing curb and gutter are to remain. Battered walls without footings are preferred to walls that utilize structural footings when possible. Edge barriers associated with this grade control can vary greatly (See Edge Barrier, 03.4).

Structural engineers are recommended for designing and detailing walls. The desired aesthetic, adjacent land use, structural integrity, and street slope should be considered when laying out and designing grade control solutions. The designer also needs to specify subgrade conditions necessary to ensure a suitable foundation for the walls and reduce the potential for settling.

	GRADE CONTROL	LoG 1	LoG 2	LoG 3	LoG 4	LoG 5
A	Thickened Edge Paving	🟢	🟢	🟢	🟠	🟠
B	Gravity Curb Wall	○	🟢	🟢	🟢	🟢
C	Structural Curb Wall	○	○	○	🟢	🟢
D	Cutoff Wall	○	○	○	🟠	🟢
E	Sloped Grade with Walk-Off	🟠	🟢	🟢	🟠	🟠
F	Sloped Grade with Thickened Edge	🟠	🟢	🟢	🟠	🟠

🟢 Appropriate 🟠 Appropriate w/ conditions ○ Not Applicable

Partial or full curtain liners may be necessary in areas of contaminated groundwater, where expansive soils pose a threat to nearby structures, or in other locations determined by a geotechnical engineer. Liners can eliminate infiltration of stormwater toward a building or road but also greatly reduce runoff reduction compared to unlined systems. For this reason, liners should not be used unless necessary for specific applications.

Figure 04.03.16

TYPE A - THICKENED EDGE PAVING

This concrete edge is a continuation of a typical adjacent concrete sidewalk that uses a singular pour and reinforced edge to retain grade. This condition is associated with instances where the landscape planter is depressed no more than 6 inches below the adjacent top of sidewalk.

LoG1 through LoG3 are typical use cases for this type of grade control. SCMs that require flat bottoms or vertical edges may utilize this approach.

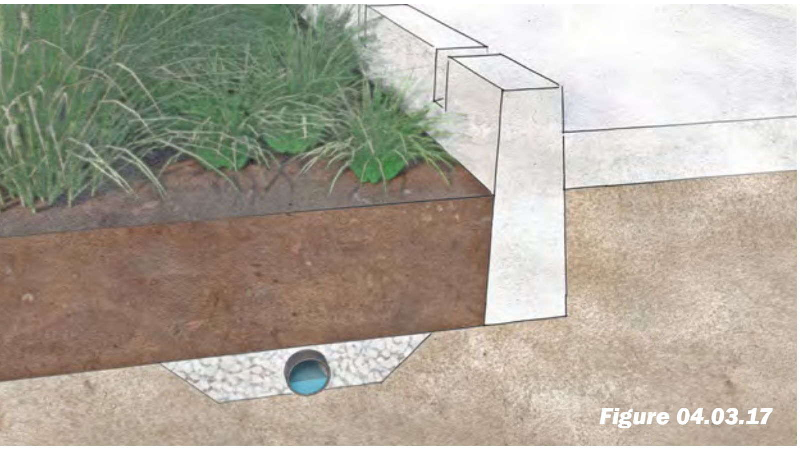


Figure 04.03.17

TYPE B - GRAVITY CURB WALL

This grade control uses an extended buried curb wall to retain grade. This is usually associated with less intensive control measures where more structural means like footings are not needed.

LoG3 through LoG5 are typical use cases for this type of grade control. SCMs that require flat bottoms or vertical edges may utilize this approach.

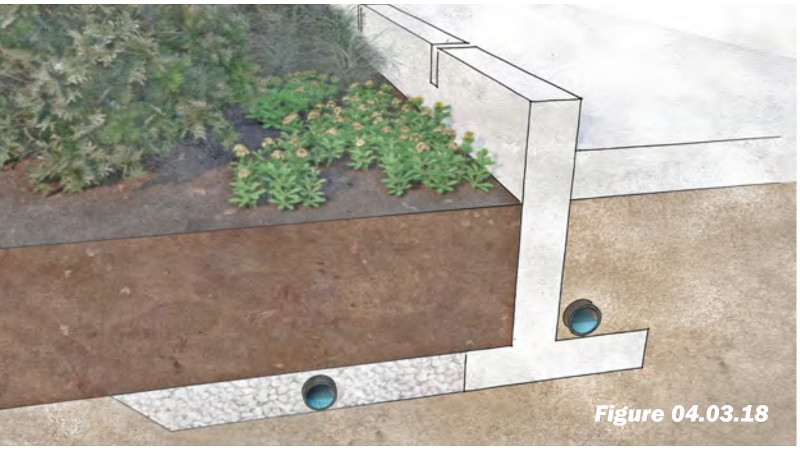


Figure 04.03.18

TYPE C - STRUCTURAL CURB WALL

Typically adjacent to a concrete sidewalk, this wall is used to retain grade and control lateral seepage when a more structural control is needed. This condition is associated with instances where the landscape planter is depressed more than 6 inches below the adjacent top of sidewalk.

LoG4 and LoG5 are typical use cases for this type of grade control. SCMs that require flat bottoms or vertical edges may utilize this approach.

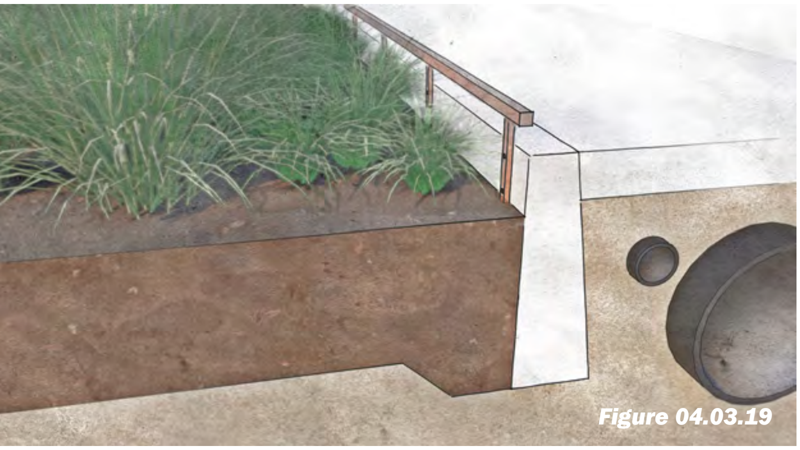


Figure 04.03.19

TYPE D - CUTOFF WALL

Using a cutoff allows for a less intensive grade control technique while addressing lateral seepage. This condition is associated with instances where the landscape planter is depressed below the adjacent gutterline and there is a desire to restrict lateral seepage.

LoG3 through LoG5 are typical use cases for this type of grade control. SCMs that require flat bottoms or vertical edges may utilize this approach.

Figure 04.03.20

TYPE E - SLOPED GRADE WITH WALK-OFF

When space allows, using slope to control grade is a cost effective and simple solution. The Type-E grade control is associated with instances where the landscape planter is depressed less than 6 inches below the adjacent top of sidewalk or street right-of-way.

LoG1 through LoG3 are typical use cases for this type of grade control. SCMs that benefit from softer approaches and sloped edges may utilize this approach.

Figure 04.03.21

TYPE F - SLOPED GRADE WITH THICKENED EDGE

This concrete edge is a continuation of a typical adjacent concrete sidewalk that uses a singular pour and reinforced edge to retain grade. This condition is associated with instances where the landscape planter is depressed no more than 6 inches below the adjacent top of sidewalk.

LoG3 through LoG5 are typical use cases for this type of grade control. SCMs that benefit from softer approaches and sloped edges may utilize this approach.

[EDGE BARRIER]

Figure 04.03.22

03.4 - EDGE BARRIER

Edge barriers are required where the finished surface of the media in a vegetated control measure is recessed below adjacent pedestrian areas with a vertical drop. A visual and physical barrier along the perimeter of a planter is necessary to discourage deliberate or inadvertent walk-off by pedestrians because the top of the planting media in the planters is recessed below the sidewalk. In addition to walk-off protection, these barriers also act as cane-able features for the visually impaired.

In general, a 4 to 6 inch high barrier is recommended adjacent to all pedestrian areas or bicycle lanes when the SCM has a vertical drop. A 15-inch high barrier should be considered on the “short” sides of the planter perpendicular to the street where vehicles may cross the pedestrian areas or bike areas. Barriers may be constructed of concrete, stone, metal railings, or a combination of a structural component and aesthetic cover. The maximum barrier height is recommended to be less than 30 inches from the top of any barrier to the surface of the recessed media.

Small openings, or curb scuppers, are necessary on any impervious area sloped toward the edge barriers (e.g., along most urban sidewalks). The scuppers allow the stormwater to drain into the facility. The openings should be full depth, 4 to 6 inches wide, and recessed a 1/2 inch below the sidewalk to ensure proper drainage and self-cleaning of sediment.

	EDGE BARRIER	LoG 1	LoG 2	LoG 3	LoG 4	LoG 5
A	Attached Barrier	🟠	🟠	🟢	🟢	🟢
B	Embedded Barrier	🟠	🟠	🟠	🟢	🟢
C	Curb Wall Barrier	○	○	🟠	🟢	🟢
D	Curb Barrier	🟢	🟢	🟠	○	○
E	Seatwall Barrier	○	🟠	🟠	🟢	🟢

🟢 Appropriate 🟠 Appropriate w/ conditions ○ Not Applicable

Scuppers are recommended at approximately 6 to 10 feet intervals and the furthest downstream opening should be at least 6 feet from the downstream end of the planter. Designers should ensure that the elevation of the downstream scupper is at least 1-inch above the finished water surface elevation to ensure that the escape route is to the street and not the sidewalk.

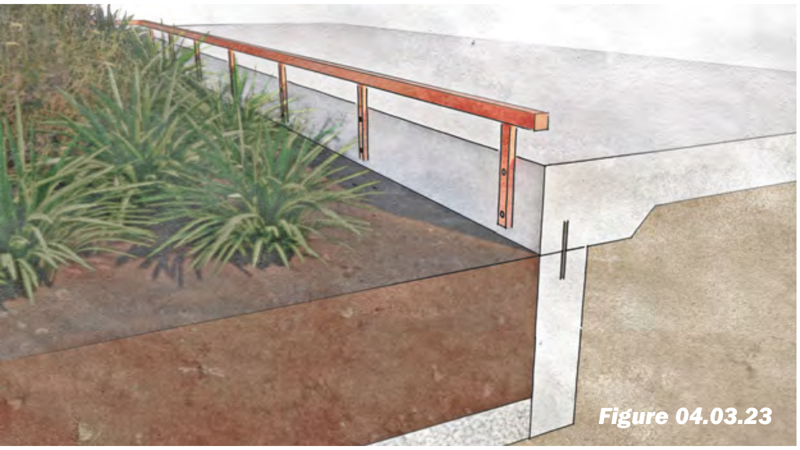


Figure 04.03.23

TYPE A - ATTACHED BARRIER

Attached barriers are mounted to the inside face of a thickened concrete planter edge or wall. They are ideal for use on space constrained projects because they do not require 12 to 14 inches for two additional containment walls.

Fastners should be structurally sound, vandal resistant, and corrosion resistant. The rail should be a minimum of 6-inches above the sidewalk and allow sidewalk runoff to drain into the SCM.

Figure 04.03.24

TYPE B - EMBEDDED BARRIER

This type of barrier is set in a flush concrete wall and is interchangable with the Curb Barrier. These barriers can be constructed of different types and sizes of tube or plate steel and can contain graphics that reflect an aesthetic package for any given project.

The barrier should be constructed and embedded so that it can be removed or repaired due to damage or maintenance needs. The rail should be a minimum of 6-inches above the adjacent sidewalk and allow drainage into the SCM.

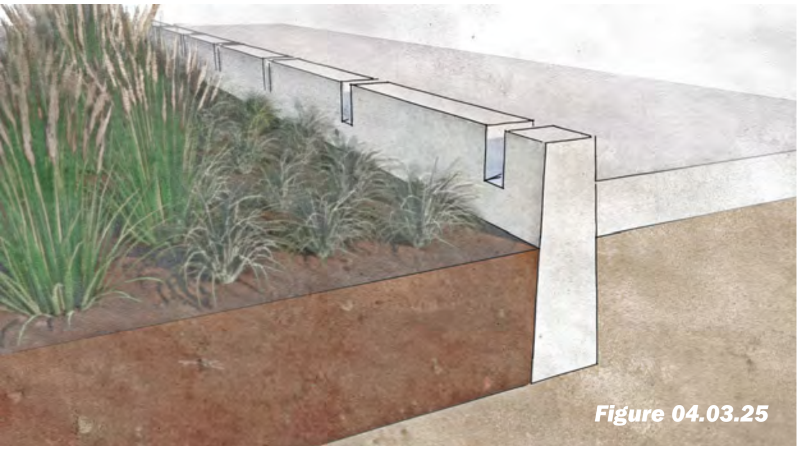


Figure 04.03.25

TYPE C - CURB WALL BARRIER

This concrete curbwall barrier is the most commonly used barrier type in SCMs. The curb wall barrier is top section of the grade control gravity curbwall and is integral to the structure of the SCM. This type of barrier is the most cost effective when integrated with a grade control structure.

Sidewalk drain scuppers should be 4-inches wide, placed every 6 to 10 feet, be extended 1/2-inch below the finished grade of the sidewalk, and sloped to drain into the facility.

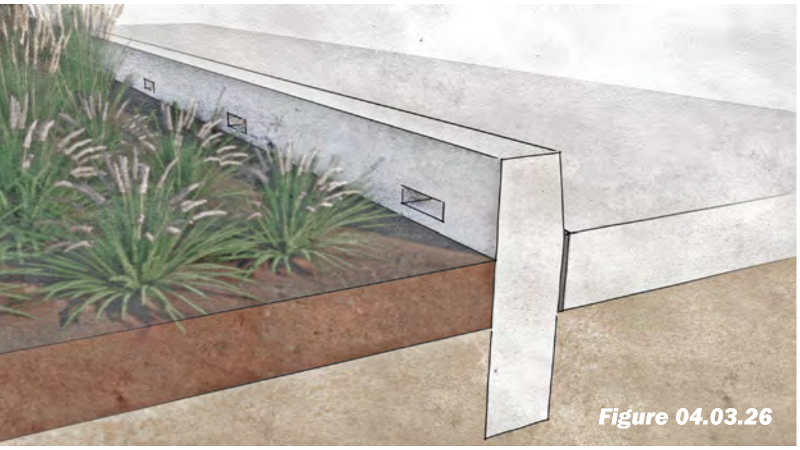


Figure 04.03.26

TYPE D - CURB BARRIER

The curb barrier is most commonly used in LoG1 or LoG2 SCMs to surround at-grade vegetated areas in dense urban settings. These types of barriers have been used in the downtown area in many locations to protect trees and the vegetated zones around them.

A key difference between historic uses and these guidelines is the inclusion of a scupper or drainage opening to allow water from the pedestrian realm to enter the SCM and infiltrate into the root zones of trees.

Figure 04.03.27

TYPE E - SEATWALL BARRIER

This type of barrier is intended to serve multiple functions such as safety barrier or as seating . Materials, dimensions, and fastening systems can vary significantly, therefore any supporting grade control beneath should be designed to support the barrier.

The difference in grade from the top of the media in the finished planter to the top of the seatwall should not exceed 30-inches.

[SUBSURFACE]

Figure 04.03.28

03.5 - SUBSURFACE

Underdrains are necessary to convey water collected after infiltration and treatment through the media to the approved outflow. Typically, this will be a city storm sewer, but occasionally may be another approved conveyance system, such as city ditches, creeks, steams, or infiltration only facilities.

Manufactured underdrains and surrounding drain rock should be limited in length and width and placed as far from the inlet and trees as possible within the control measure. A minimum distance of 10-feet between the edge of the drain rock surrounding the underdrain and any trees and inlets is recommended.

The underdrain should utilize narrow slotted openings (typically found in wellscreen pipes) and the total opening area should be adequate to ensure proper drainage and draw down times. Typically, this will result in a 4 to 6 foot long slotted drainline that ties into the control structure and then outfalls to the city storm sewer. All underdrains shall meet applicable City criteria and requirements for cleanouts.

Underdrains shall be surrounded in a clean washed drain rock aggregate that is appropriately sized to prevent migration of media and clogging of the slotted openings. Geotextile filter fabrics are not permitted to be used to separate media layers, but step-down or “choker course” approaches may be utilized to reduce the likelihood of media migration.

SUBSURFACE		LoG 1	LoG 2	LoG 3	LoG 4	LoG 5
A	Underdrain to Storm Sewer	○	○	🟠	🟠	🟢
B	Infiltration Only	🟢	🟢	🟠	🟢	🟠
C	Partial or Fully Lined	○	○	○	🟠	🟢
D	Structural Cells	🟠	🟢	🟢	🟢	🟠

🟢 Appropriate 🟠 Appropriate w/ conditions ○ Not Applicable

Figure 04.03.29

TYPE A - UNDERDRAIN TO STORM SEWER

LoG 4 and 5 facilities may require a slotted underdrain to collect and convey water, through a control structure, to the nearest storm sewer or other approved conveyance structure.

The underdrain should be surround in a gravel drainage layer 2X the diameter in depth and by a minimum of 12-inches on all sides. Underdrain design may be influenced by rates of infiltration into the native subgrade.

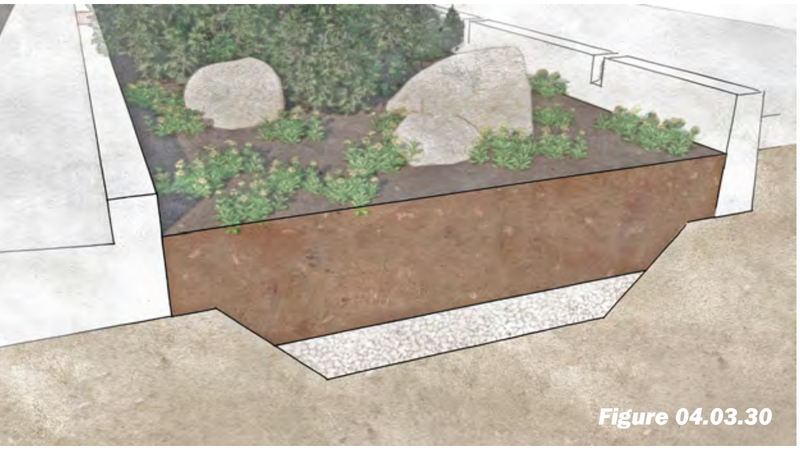


Figure 04.03.30

TYPE B - INFILTRATION ONLY

LoG 1 through 4 all have some element of infiltration only. Depending on the size of the tributary area and the infiltration capacity of the soil, media, and subsurface, there may need to be an additional gravel drainage layer to store small volumes of water to reduce the amount of time water is exposed on the surface during small storm events.

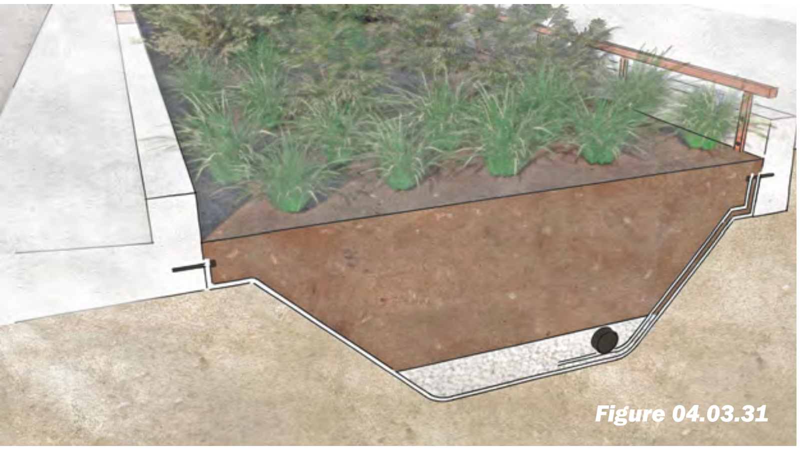


Figure 04.03.31

TYPE C - PARTIAL OR FULLY LINED

Facilities that need to be located over contaminated soils, shallow groundwater, utilities that need to be protected, or are located near building basements may need to be partially or fully lined. A minimum 30mil HDPE, or equivalent, liner should be used.

The liner should be attached to a concrete wall or structural curb so that it can be securely fastened and waterproofed.

When fully lined, additional soil volume may be necessary to provide plant material with adequate growing room.

Figure 04.03.32

TYPE D - STRUCTURAL CELLS

Structural cells have two primary uses cases; to help create large, uncompacted soil volumes and to create subsurface voids for significant stormwater storage capacity.

The Ultra Urban Green Infrastructure Guidelines include a Tree Trench SCM that utilizes a hybrid approach of providing soil volume with minimal storage below the paved surface but above the media.

[OVERFLOW]

Figure 04.03.33

03.6 - OVERFLOW

Overflow control is an essential part of all stormwater control measures. The overflow may be passive and only be engaged during a larger storm event, or can be active by controlling the level of stormwater to enhance runoff reduction or water quality.

Passive over flow structures are appropriate for LoG1, LoG2, and LoG3 control measures where there are no underdrains or subsurface conveyance of stormwater. Cub notches and curb cuts are typically used on these type of SCMs.

Active overflow structures, either pre-fabricated or constructed on site, are primarily used on LoG4 and LoG 5 facilities to control the water surface levels and release rate of the stormwater stored in the facility to help meet regulatory requirements. They can also be located and sized to help encourage infiltration by varying orifice depth, size, and location in relation to underdrains and outlets.

Outlets may also be simple curb cuts or notches to act as escape routes to protect other nearby buildings or features by directing large events back to street curb and gutter. Additionally, weir walls are considered overflow structures between cells in facilities that are designed in-series to reduce overflow runoff to streets and contain larger storm events. Erosion may be a concern when using weir walls, so additional energy dissipation (rip-rap or concrete pads) may be necessary.

OVERFLOW		LoG 1	LoG 2	LoG 3	LoG 4	LoG 5
A	Curb Notch	🟠	🟠	🟠	🟢	🟢
B	Weir Wall	○	○	○	🟢	🟢
C	Curb Cut with Wheel Protection	○	○	🟢	🟢	🟠
D	Atrium Overflow & Orifice	○	○	○	🟠	🟢
E	Manufactured Overflow & Orifice	○	○	○	🟠	🟢
🟢	Appropriate 🟠	Appropriate w/ conditions	○	Not Applicable		

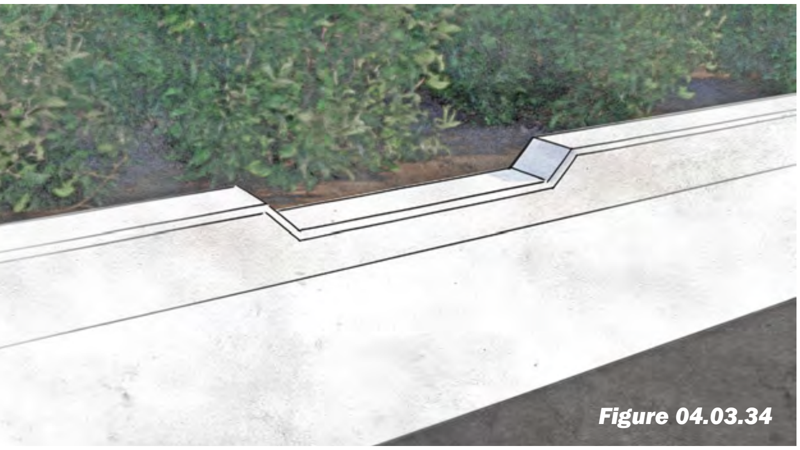


Figure 04.03.34

TYPE A - CURB NOTCH

A curb notch is considered a passive overflow intended to ensure a maximum water level that is typically above the water surface elevation (WSE) but intended to protect adjacent features from overflowing stormwater.

The curb notch should be below the elevation of the lowest downstream scupper in any barrier and direct water back to the curb and gutter when possible.

The curb notch should be between 1 and 3 inches below the top of curb. If a deeper notch is necessary, see Type C below.

Figure 04.03.35

TYPE B - WEIR (BETWEEN CELLS)

A weir wall, also known as a checkdam, is an important overflow component in a multi-cell control measure or in a series of connected control measures. Typically a weir wall will establish the water surface elevation (WSE) instead of the inlet to ensure that water flows to the next cell. Weir walls can also be used to control grade when longitudinal slopes are steep, and should be spaced at least 10’ apart.

Weir walls can be constructed of concrete, stone, steel, or UV stable materials.

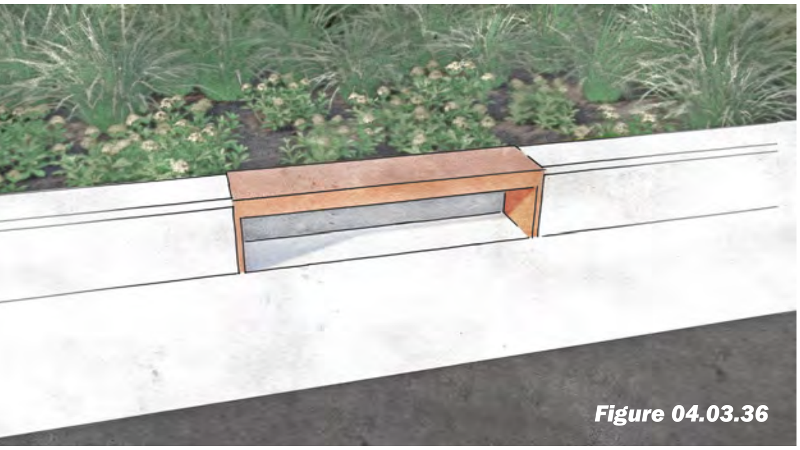


Figure 04.03.36

TYPE C - CURB CUT WITH WHEEL PROTECTION

When a Type A curb notch is not deep enough to provide the overflow necessary, the designer may elect to utilize a full-depth curb cut.

Because the curb cut is full depth, it is necessary to provide wheel and snow plow protection by utilizing a pre-fabricated steel “staple”. This component is very similar in function to the Type C Inlet and will also allow stormwater to enter the facility. It does not require a sunken gutter line as Type C Inlet does, although the grade in the facility should be carefully considered to ensure that the overflow is engaged properly.

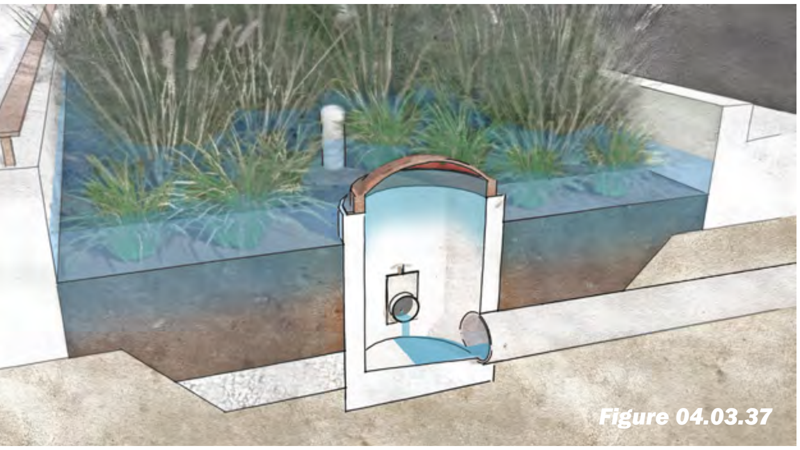


Figure 04.03.37

TYPE D - ATRIUM OVERFLOW & ORIFICE

A control structure acts as an overflow device for control measures that include an underdrain to convey treated stormwater. The control structure typically includes an orifice sized to allow the full volume a control structure to drain in 12 hours or less.

A Type D overflow utilizes a gate valve with an orifice plate to control flow and the rim of the atrium grate controls the water surface elevation (WSE). This type of structure also acts as an internal overflow rather than directing overflows back into the street.

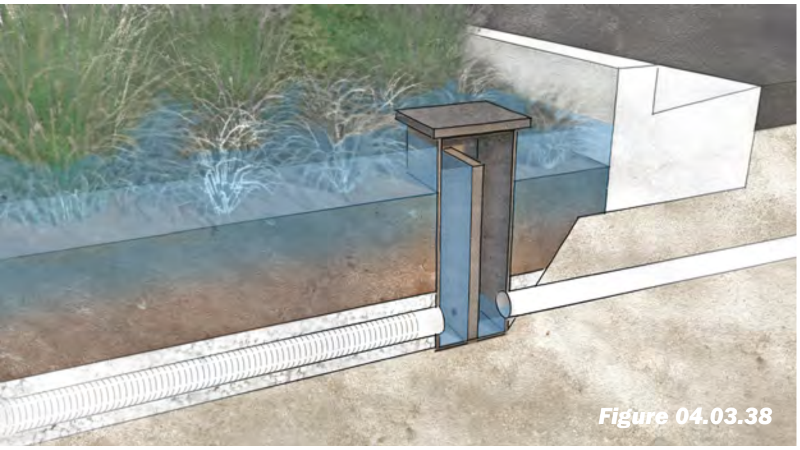


Figure 04.03.38

TYPE E - MANUFACTURED OVERFLOW & ORIFICE

A manufactured control structure functions very similiarly to a site constructed structure. The orifice is typically drilled into a plate or stop-log that also controls an internal overflow elevation. Some devices include overflow grates on top of the structures to allow internal overflow, but others do not. These types of devices work best on control measures that can overflow back to the street gutter.

Chapter FIVE

APPLICATION OF STRATEGIES

01 - INTRODUCTION

This chapter of *Denver's Green Continuum: Streets* is a guide to help project owners and their partners apply the concepts of the Green Continuum during project planning and design. It is not a guide for project prioritization, it assumes that a project has already been identified and it provides guidelines for integrating green infrastructure into that project. However, during project prioritization it is strongly encouraged that the Department of Transportation and Infrastructure's Equity Index (Figure 05.01.1) be used to identify areas of the city in need of infrastructure investment, and that projects in these areas be elevated for implementation. The benefits that green infrastructure provides (e.g., heat mitigation, air quality improvement, and enhanced streetscapes) are the same infrastructure services needed in locations where DOTI's Equity Index is highest. The Equity Index Map in Figure 05.01.1 tracks closely with metrics of urban heat and water quality discussed throughout this document and mapped later in Chapter 5, Section 02. Therefore, choosing to pursue projects in these areas and including green infrastructure is an excellent way to invest in these areas.

This document does not provide guidance for the construction or operation and maintenance phases of a project's life cycle. The blueprint highlights important actions to integrate Green Continuum concepts.

As the name implies, the *Green Continuum: Streets* is tailored for right-of-way (ROW) projects. The Green Continuum guidelines apply to capital improvement projects funded by the City and County of Denver (CCD). Following the guidelines on capital projects will produce benefits that protect and enhance the community's shared natural and built environments. Therefore, the Green Continuum should not be viewed as a guide to meet *minimum* standards, rather it is a toolbox to *maximize* the benefits provided to Denver citizens by green infrastructure given

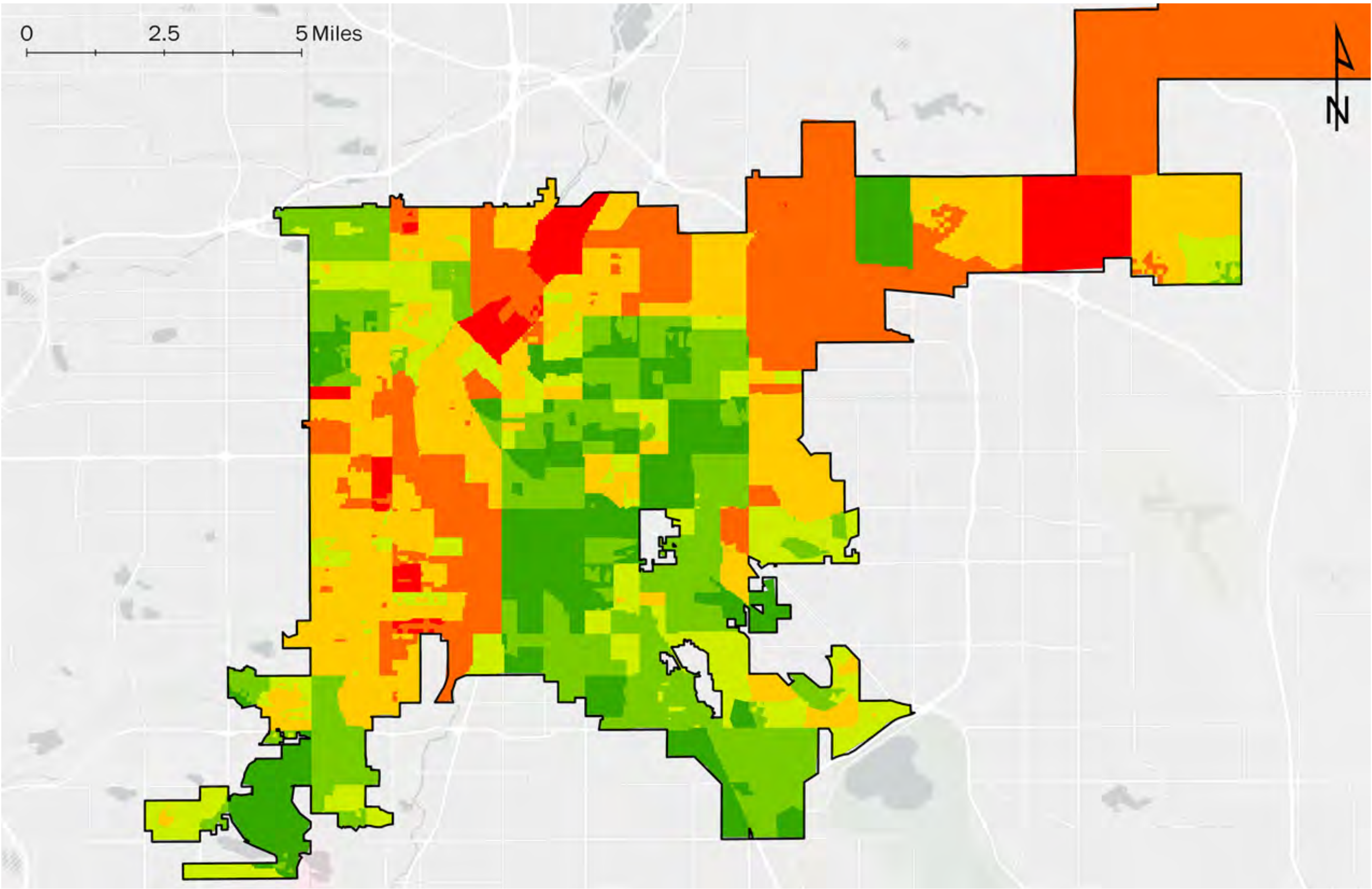


Figure 05.01.1 : Department of Transportation and Infrastructure's (DOTI) Equity Index. Higher numbers and warmer colors indicated areas in greater need of infrastructure investment. (as of March 2021)

project objectives and constraints.

This section is segmented into two phases. The first is the planning phase, and the outcome is to identify the Level or Levels of Green (LoG) that are preferred for the street given the project type, surface temperatures, anticipated runoff water quality, and flood risk. The second phase is the design phase which highlights important green infrastructure considerations that fit into the overall design process.

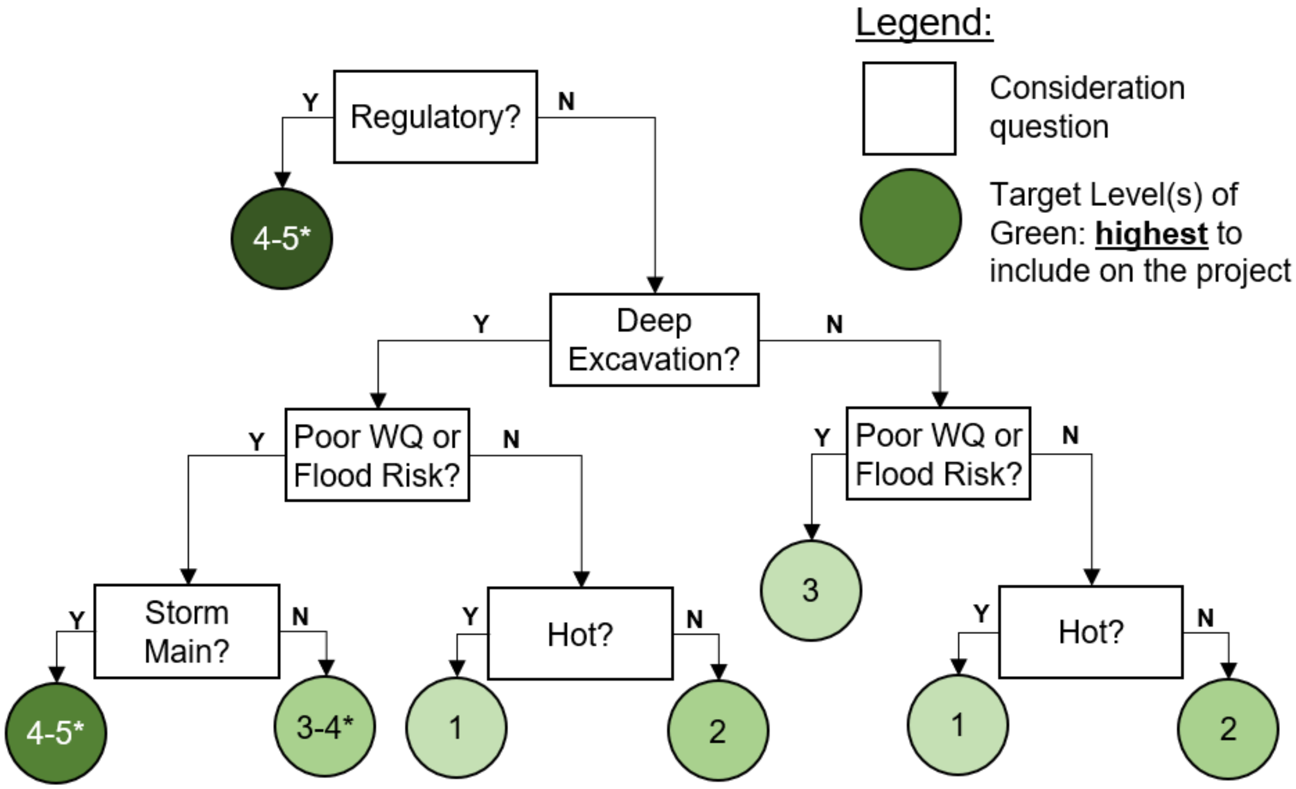
02 - PLANNING

02.1 - TARGETING A LEVEL OF GREEN

When a concept plan is being developed, the project owner should consider the project's priorities, construction impacts, and location to identify a target Level of Green (LoG) for the project. The target LoG is the highest Level of Green that should be included that will address the project's priorities. LoGs lower than the target LoG can also be implemented to accomplish multiple goals or to improve the streetscape. By answering the following questions, the project owner is guided to a target Level of Green:

- Does the project have a regulatory requirement to prevent water quality impacts?
- Does the project require deep (>2 ft) excavation?
- Is the project in a poor water quality area?
- Is the project in an area with elevated flood risk?
- Is the project on a street with temperatures in the highest 25 percentile?
- Is there subsurface stormwater drainage infrastructure on street?

These questions are described in the subsections below with resources and guidance for project managers to answer "Yes" or "No" to the questions listed above. With answers to these six questions, project managers can follow the flow chart on the next page (Figure 05.2.1) to arrive at the target LoG for their project. To aid in the planning process, the considerations have been mapped and the flow chart has been followed for each street segment in the city. This



*Soils with low infiltration capacity preclude use of Level of Green 4. Geotechnical investigation required.

Figure 05.02.1: Planning flow chart to determine the target Level(s) of Green for the right-of-way project

results in two final Levels of Green Strategy Maps which show the target LoG for each street segment later in this section. Digital versions of the Levels of Green Strategy Maps are also available online in MapIt Denver. This section also includes examples of how Levels of Green lower than the target LoG can be incorporated on the project to build better streetscapes and address multiple project priorities. Finally, site context, including soil conditions, will further refine the LoG or LoGs chosen. This is discussed in the next section on Design.

02.2 - REGULATORY REQUIREMENT

Projects that trigger a post-construction regulatory requirement for water quality treatment under CCD's Municipal Separated Storm Sewer System (MS4) permit[1] are required to implement stormwater control measures (SCM) that meet the design standards of the permit. Project owners are referred to the permit and/or the CCD Wastewater Management Division's MS4 team to determine if their project has this requirement. If a project does have a regulatory requirement, Level of Green 5 SCMs as described in *Denver's Ultra Urban Green Infrastructure Guidelines* will most likely be used. Level of Green 4 SCMs may also be used to meet the MS4 permit's Runoff Reduction post-construction water quality control pathway, but only after careful consideration of infiltration rates into the native subgrade.

02.3 - SOILS

A comprehensive soils map does not exist for CCD and soils in urban environments are highly spatially variable. Therefore, soil type is not included in the planning considerations for selecting a Level of Green because they cannot be known without a geotechnical investigation. However, soil class, gradation, and infiltration capacity are a very important consideration for selecting a Level of Green. Level of Green 4 SCMs that do not have underdrains are not appropriate if infiltration rates into the native subgrade are <1.0 in/hr, and rates >2.0 in/hr are preferred.

Existing soils should be evaluated for infiltration capacity and the ability to support plant life (i.e, nutrients, organic content,

Excavation Depth	**Example ROW Construction Activities**	**Appropriate Levels of Green**
Deep (>2 ft)	Storm and sanitary pipe projects; road construction; construction on adjacent properties impacting ROW; major underground utility projects	Level of Green 3-5
Shallow (< 2 ft)	Curb ramp replacement; curb and gutter replacement; installation of lighting, signals; addition of traffic islands and medians; improvement of landscape area or tree lawns; sidewalk construction or rehabilitation; intersection improvements; road repaving	Level of Green 1-3
None	Maintenance or signage, striping, meters, bike parking; Street sweeping; Storm/sanitary lining, plugging, and inspection; Bridge maintenance	None

Table 05.02.1: Example construction activities for Levels of Green for project excavation depths. All projects determine LoG through the One Build process.

pH values, etc.). Soils are also discussed in Chapter 4 in relation to SCMs and components.

02.4 - EXCAVATION TYPE

The SCMs in higher Levels of Green require more excavation during construction than those in lower Levels. Similarly, excavation requires additional steps in the design process to identify, protect, and relocate utilities. Therefore, it is best to include higher Level SCMs on projects that already have “deep” (>2 ft) excavation planned for the economies of scale. Conversely, lower Levels of Green are best paired with projects with “shallow” excavation (<2 ft), as this is an excellent opportunity to replace or expand pervious area.

Table 05.02.1 lists example ROW construction activities and the appropriate Levels of Green for projects with deep, shallow, and no excavation. Projects are expected to work with the Office of Green Infrastructure through the One Build process to determine athe appropriate Level of Green.

02.5 - STORMWATER INFRASTRUCTURE

The presence of underground stormwater drainage infrastructure is an important consideration when selecting a Level of Green. Levels of Green 1-3 do not require any stormwater infrastructure as they spill out back to the street once full of water, so they can be used if stormwater infrastructure is present or not. Levels of Green 4 and 5 both can include underdrains, which require a connection to stormwater drainage infrastructure. It is recommended that Level of Green 4 do not include underdrains to encourage deep infiltration and that Level of Green 5 does have an underdrain.

If a ROW project in on street segment that does not have stormwater drainage infrastructure, it precludes using Level of Green 5 SCMs in favor of a Level of Green 3 or 4 if flood control and water quality treatment are project priorities. If soil infiltration capacity is low (<1.0 in/hr), it may preclude the use of Level of Green 4 SCMs. If flood control and water quality are less important, than Levels of Green 1-3 can be used with or without stormwater infrastructure.

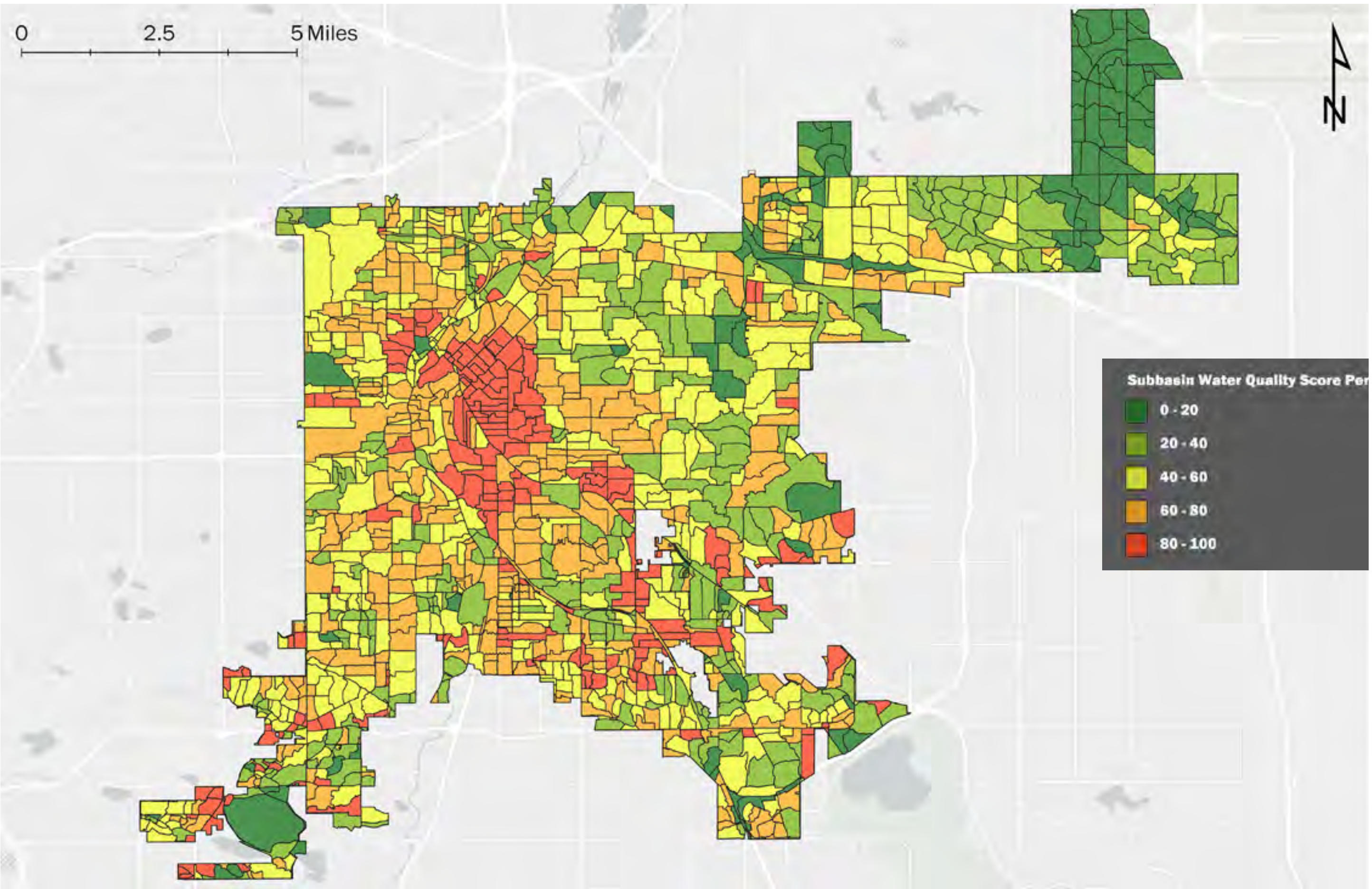


Figure 05.02.2: City of Denver Sub-basins water quality score groups (as of March 2021)

02.6 - POOR WATER QUALITY AREA

A 2015 geospatial analysis[2] divided CCD into 31 drainage basins which were scored on their potential for implementing SCMs. The scores included both primary criteria that characterized stormwater runoff and pollution and secondary criteria that described the need for heat island mitigation, greenspace, and equitable investments.

This scoring framework has been adopted for the *Green Continuum: Streets*. Here the city is divided into 1459 sub-basins, which are given a water quality score specifically for right-of-way green infrastructure based on the sub-basin's land use, impervious cover, downstream treatment, and downstream regulations (Table 05.02.1). Higher scores indicate poorer water quality. The 25% of sub-basins with the highest scores were deemed as in a poor water quality area (Figure 05.02.2). The secondary principles of heat and equity are not accounted for in this water quality score as was done in the 2015 analysis because they are included explicitly elsewhere in this planning framework.

If a right-of-way project is in an area of poor water quality, the project is generally directed toward a Level of Green 4 or 5, as these SCMs will provide more water quality treatment. LoG3 SCMs may also be appropriate if there is no stormwater infrastructure and soil infiltration capacity is low.

Primary Categories	**Score**	**Notes**
Existing TMDL downstream	10	10 = yes; 0 = no (inherit from WQ Priority Scorecard2)
303(d) listed waterbody	10	10 = yes; 0 = no (inherit from WQ Priority Scorecard2)
Wet weather pollutant loading (4 subcategories: TSS, P, N, Bacteria)	80 (4 x 20)	Use land use class and % impervious cover to estimate loads of each pollutant.
Existing treatment	0.85x - – 1.00x	Scale back score of sub-basin by 0% if no treatment, up to 15% if fully treated
Maximum Possible	100	

Table 05.02.1: Summary of Sub-basin Water Quality Scoring for Green Streets

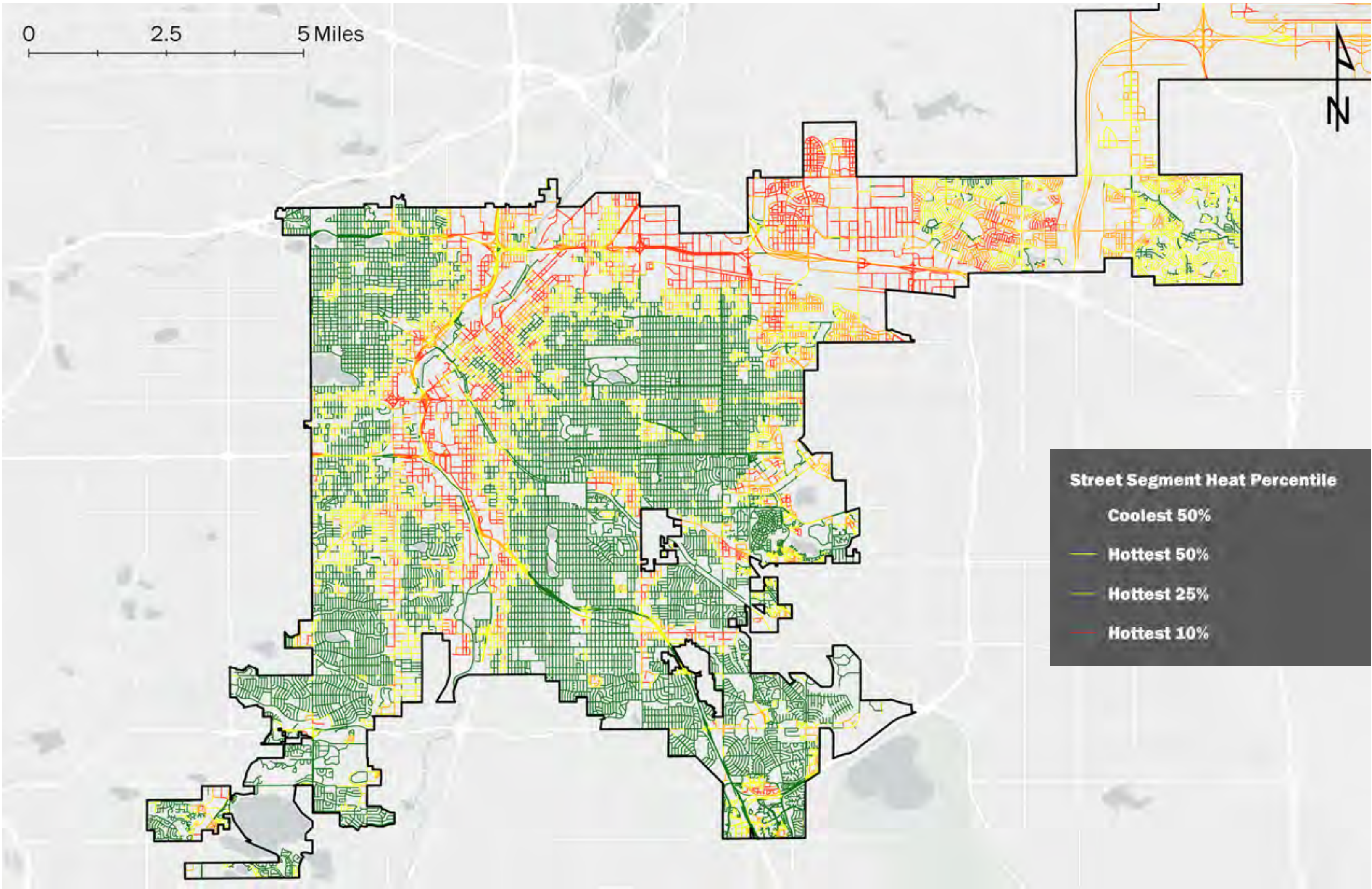


Figure 05.02.3: Denver City streets ranked by maximum annual land surface temperatures derived from LANDSAT satellite imagery, composited across the years 2000 to 2019

02.7 - HOT STREET

Green infrastructure can mitigate urban heat island by providing shade and evaporative cooling. Therefore, it should be targeted in areas of the city where the urban heat island is most severe. LANDSAT satellite observations of surface temperature through time are used to identify which streets in Denver experience the hottest temperatures (See Appendix 3.02 for methodology). Surface temperatures are usedbecause:

- It measures temperatures on the ground and accounts for the cooling effects of shade provided by trees and buildings and the heating effects of direct sun exposure, and;
- The satellite measurements cover the entire footprint of the city and are logged once every 16 days.

Figure 05.02.3 shows the streets in Denver, color coded by relative land surface temperatures measured by LANDSAT. The red streets represent the hottest 10% of street segments in the city, orange streets the hottest 25% of street segments, and yellow the hottest 50% of street segments in the city.

If a right-of-way project is on a street segment that is in the hottest 25 percentile, indicated by an orange or red color in Figure 05.02.5, then the project will benefit most from using green infrastructure to enhance canopy and provide shade. Therefore, projects on hot streets without a strong water quality driver are directed toward Level of Green 1 or 2, which includes SCMs that maximize tree canopy coverage and health.

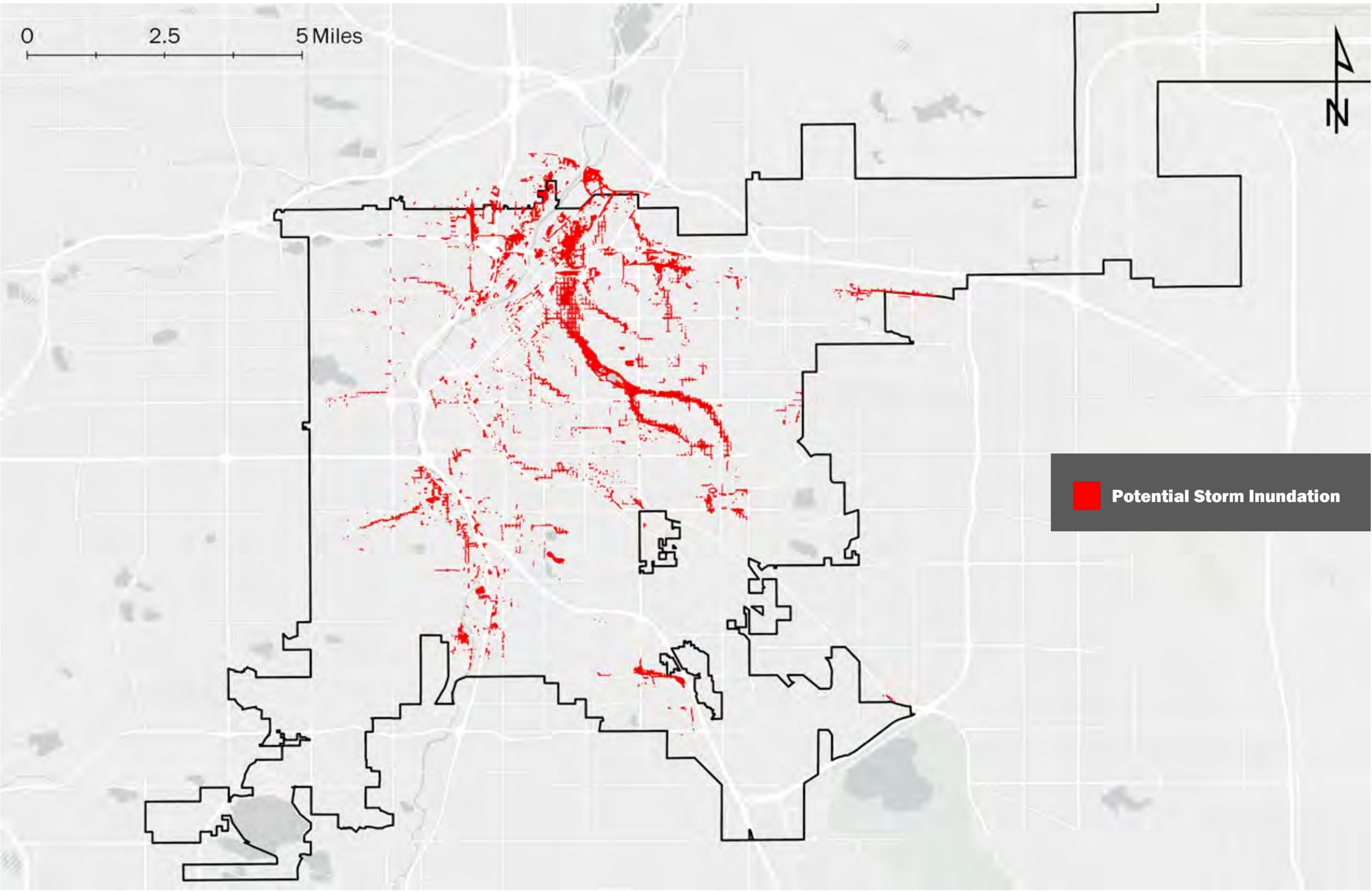


Figure 05.02.4: Denver City Streets prone to storm inundation flooding (as of March 2021)

02.8 - FLOOD PRONE AREA

Stormwater control measures, especially those in LoG 3-5, are intended and expected to mitigate nuisance flooding from smaller return period storms, such as the 2-yr storm. As part of its storm drainage master plan, CCD Wastewater Management Division has created a Flood Risk Inundation Map (See Figure 05.02.4) of areas of the city that are likely to flood during the 100-yr storm[3]. It has not done the same analysis for smaller return period storms. Therefore, the 100-yr flood risk identification map is used to identify areas that are good candidates for flood mitigation with LoG 3- 5 SCMs, on the assumption that areas that flood during the 100-yr event are also more likely to flood during smaller events.

If a ROW project is in an area at risk of flooding, green infrastructure techniques that store runoff volume can help address this issue. Therefore, projects on flood prone streets will be directed to higher Levels of Green. LoG 4-5 include SCMs that provide the volume storage needed to reduce flooding.

02.9 - FINAL LEVEL-OF-GREEN MAPS

Data sources discussed related to water quality, flood risk, heat, and stormwater infrastructure were combined with the logic of the flow chart of Figure 05.02.1 to create two Stategy Maps with recommendations for projects with shallow excavation in the ROW (Figure 05.02.5) and projects with deep excavation in the ROW (Figure 05.02.6). Two Strategy Maps are shown, because the results depend on whether the project requires shallow or deep excavation. No map is being shown for projects with regulatory requirements, because those can only result in Level of Green 4 or 5. These maps indicate the target LoGs to address heat and stormwater priorities of each street. LoGs lower than the target LoG can also be included on the project to achieve multiple benefits. The subsection that follows will provide further guidance for using multiple Levels of Green on a single project to meet multiple goals and improve street corridor design.

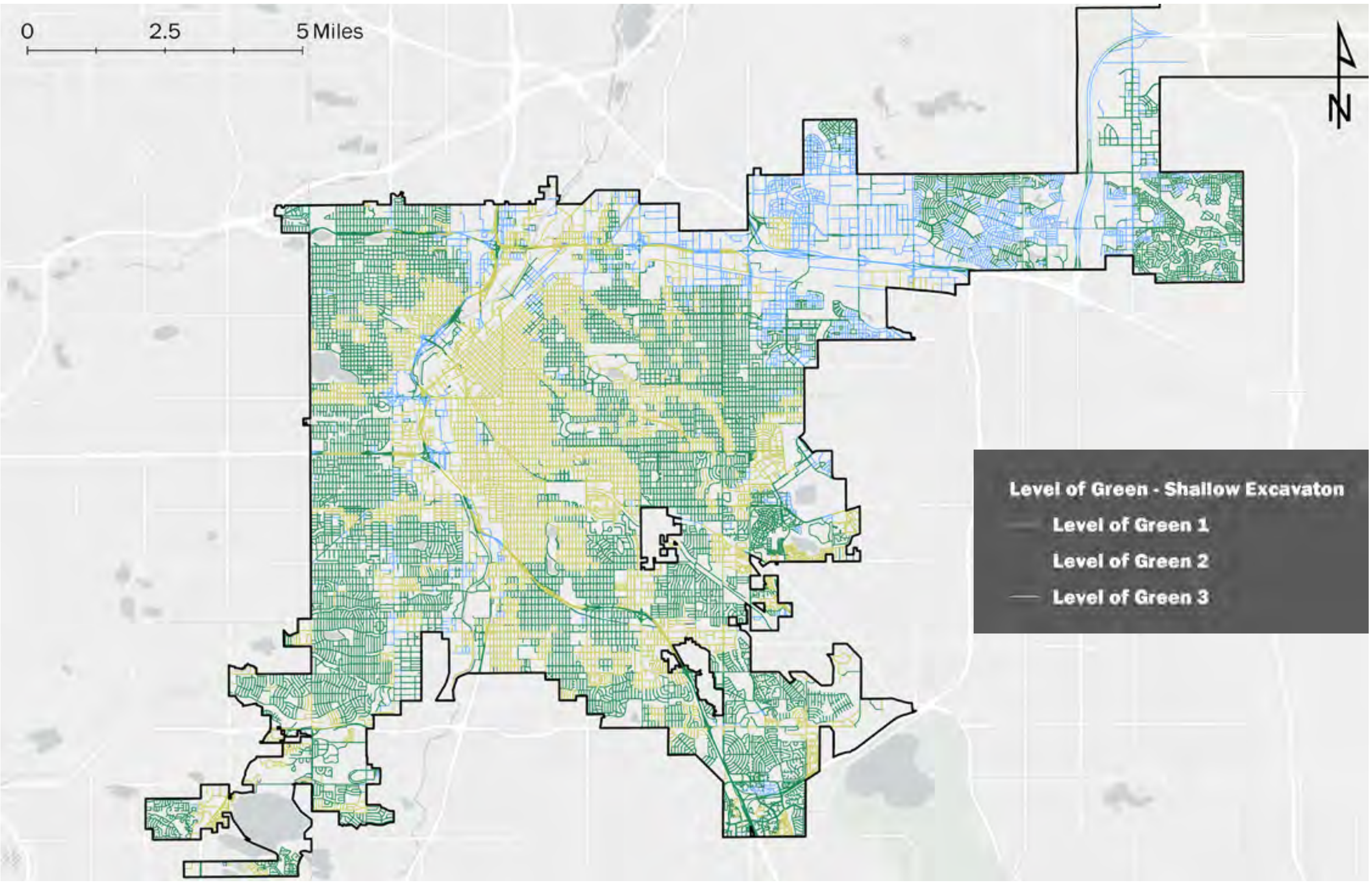


Figure 05.02.5: Level of Green Strategy Map - For Projects With Shallow or No Excavation in the ROW (LoG1 through LoG3)

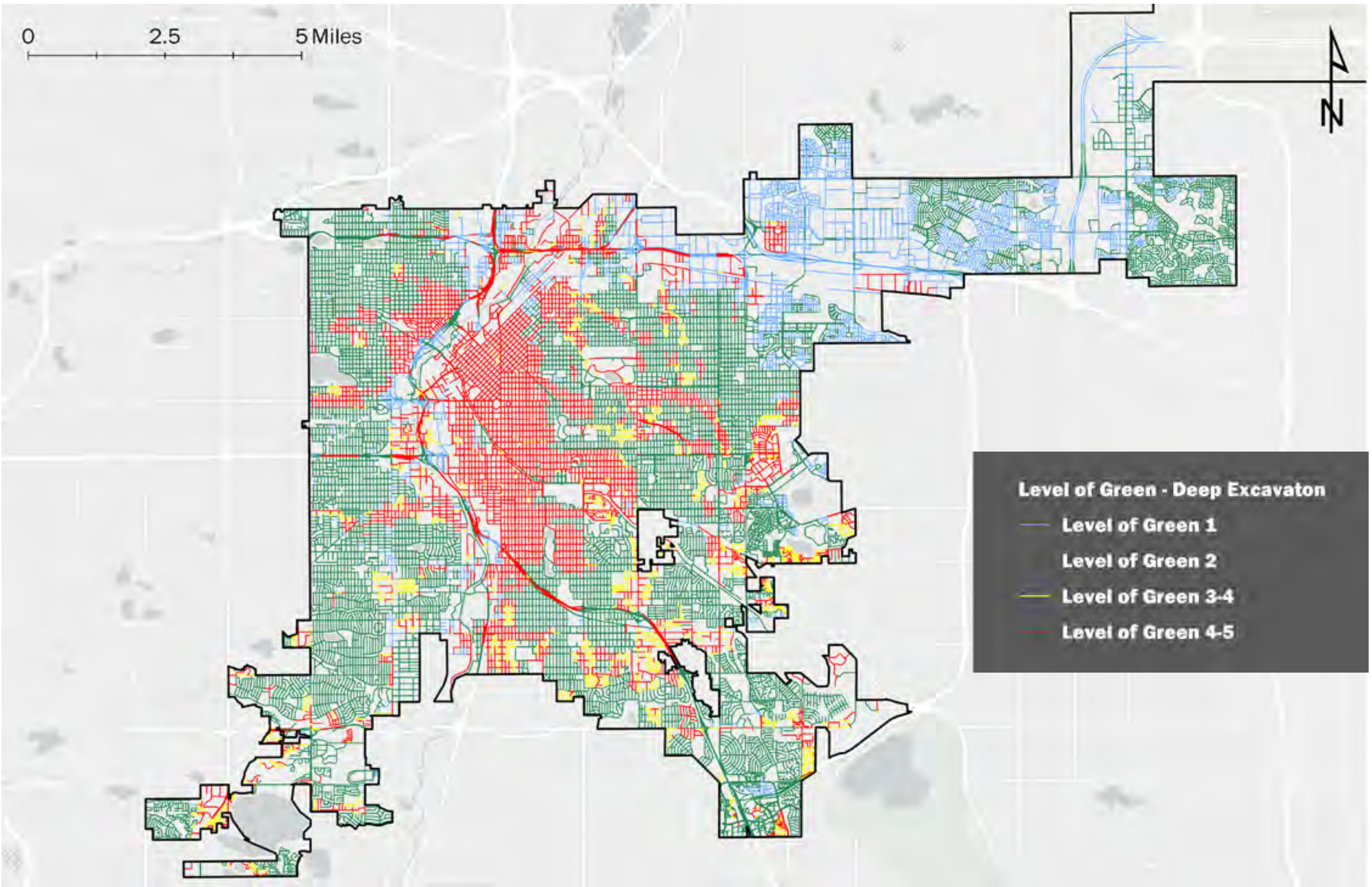
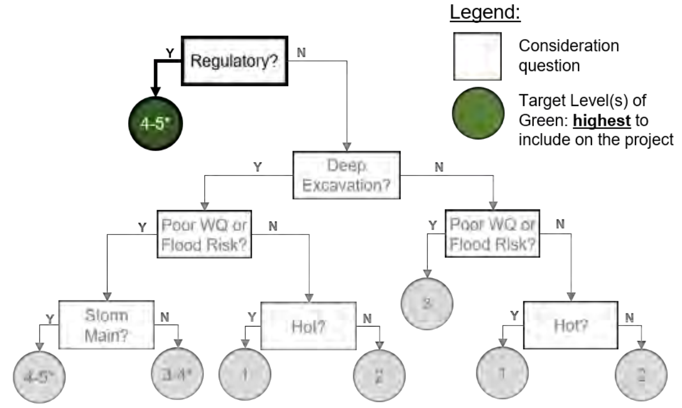


Figure 05.02.6: Level of Green Strategy Map - For Projects With Deep Excavation in the ROW (LoG1 through LoG5)

02.10 - PLANNING ALTERNATIVE CASE STUDIES

The Planning section identified a target LoG for each street segment based on the heat and stormwater management needs. The target LoG is the highest Level to include on a project, however lower Levels can be used to improve the quality and performance of the street landscape. This section shows examples of using multiple LoGs on one project to meet a single objective more efficiently, to meet multiple objectives, and to maintain a consistent, high quality urban design throughout the street corridor. The examples show one or two blocks and identify a limited number of project constraints to keep the focus on the benefits of combining multiple Levels of Green.



*Soils with low infiltration capacity preclude use of Level of Green 4. Geotechnical investigation required.

Figure 05.02.7: Flow chart for Case Study 1, with LoG4-5 as the target highest LoG to include on the project

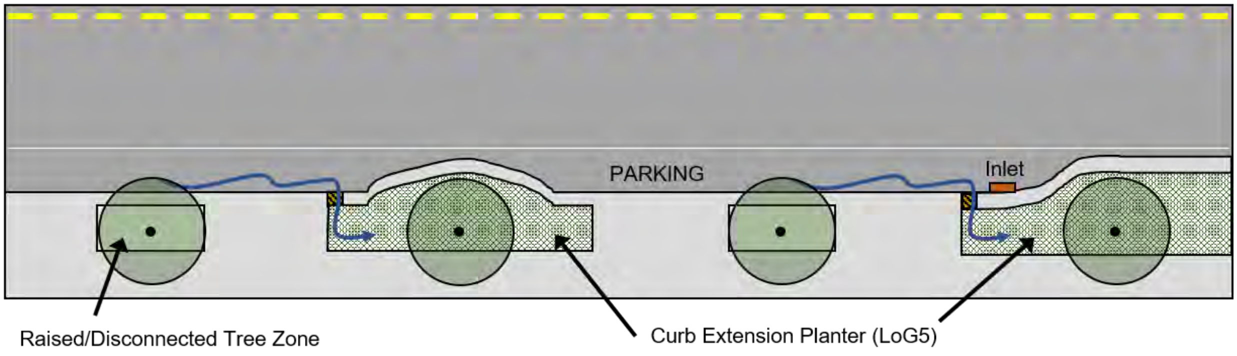
CASE STUDY 1: PROJECT HAS REGULATORY REQUIREMENTS

This example project has triggered the regulatory requirement to store the water quality capture volume (WQCV). Following the flowchart in the Planning section suggests targeting LoG4-5 (Figure 05.02.7). The street has a storm main running beneath it, and a geotechnical investigation revealed that infiltration rates in the native soils are all <0.5 in/hr. Therefore, LoG5 is selected as the target LoG for the project because of the soils and the ability to use underdrains. The street runs through a commercial area where parking is important for businesses and their customers.

Alternative 1 (Figure 05.02.8a) includes two stormwater Curb Extension Planters (LoG) that store the WQCV. Curb extension extend into the parking lane allowing the project to manage the WQCV with only two SCMs. Two trees are included to provide shade for the corridor and are bordered by a 6” curb preventing stormwater flow from the sidewalk to enter.

Alternative 2 (Figure 05.02.8b) includes four Recessed Tree Zone SCMs, which are LoG2 facilities receiving runoff from the adjacent sidewalk. Increasing the pervious area and disconnecting the sidewalk impervious area reduces the volume requirement. Therefore, the footprint of the LoG5 facilities can be reduced, and two Streetside Stormwater Planters can be used. Using LoG2 and LoG5 SCMs together allows the project to meet its requirements, maintain parking, and increase tree canopy in a commercial area.

(a) Alternative 1: Single Level of Green



(b) Alternative 2: Multiple Levels of Green

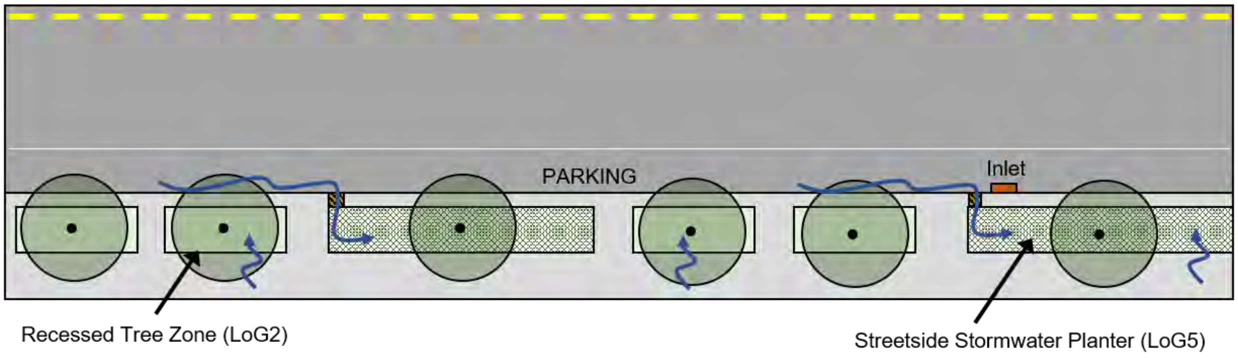
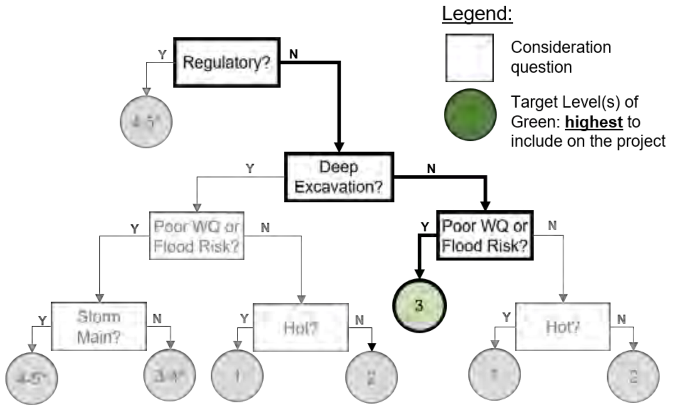


Figure 05.02.8: Alternatives for Case Study 1 using (a) one and (b) multiple Levels of Green

CASE STUDY 2: MULTIPLE PROJECT PRIORITIES

This example project is a sidewalk removal and replacement on a residential street with a bike lane. The street is both in a Poor Water Quality Area and on a Hot Street. Since replacing the sidewalk requires shallow excavation, the flowchart in the Planning section suggests targeting LoG3 SCMs (Figure 05.02.9) because LoG3 SCMs provide simultaneous water quality and heat mitigation benefits.



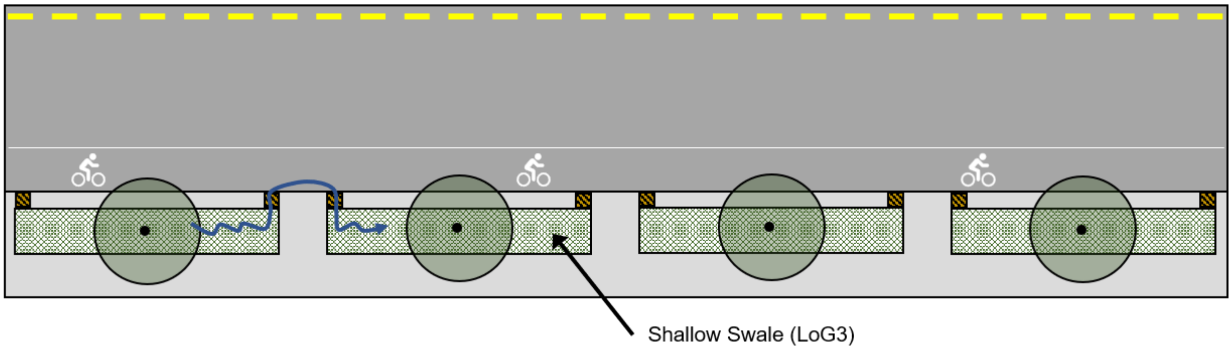
*Soils with low infiltration capacity preclude use of Level of Green 4. Geotechnical investigation required.

Figure 05.02.9: Flow chart for Case Study 2, with LoG3 as the target highest LoG to include on the project

Alternative 1 (Figure 05.02.10a) includes four Shallow Swale SCMs (LoG3) that provide treatment of runoff from the road and sidewalk as it flows through the pervious area. The run-on ratio criteria of LoG3 SCMs indicate that four swales are needed on the project, which allows for planting four trees on the street.

Alternative 2 (Figure.05.02.10b) uses two Tree Lawn Swales (LoG2) in between three Shallow Swale SCMs (LoG3). The increased pervious area and disconnection of sidewalk impervious area by the Tree Lawn Swales dictates only three Shallow Swale SCMs, given run-on ratio criteria. Because the sidewalk is being removed and replaced, additional construction impacts of adding the Tree Lawn Swales is not significant, but the canopy coverage increases by 25% which helps address the urban heat issues. Additionally, costs associated with the inlet and outlet works of the fourth Shallow Swale SCM are avoided. Using rectangular swales for all SCMs also leads to a consistent urban design that uses less concrete.

(a) Alternative 1: Single Level of Green



(b) Alternative 2: Multiple Levels of Green

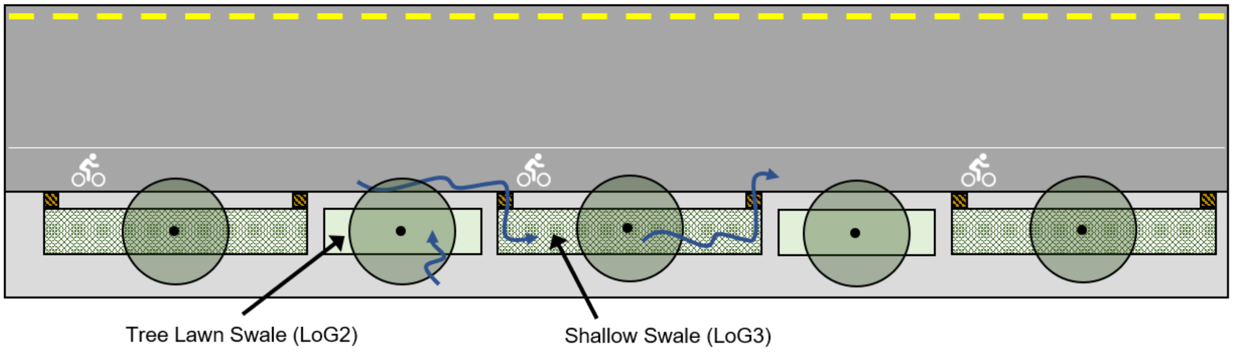
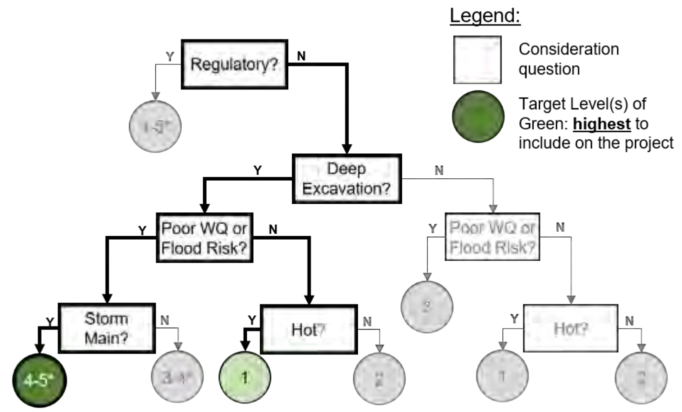


Figure 05.02.10: Alternatives for Case Study 2 using (a) one and (b) multiple Levels of Green

CASE STUDY 3: BLOCK-BY-BLOCK PRIORITIES

This example project is a replacement of an undersized storm sewer the runs beneath the street. The existing pipe has insufficient capacity given the rapid impervious cover growth on private property in the basin that it drains. The pipe replacement project will require deep excavation and run several blocks, some of which are in flood prone areas and some of which experience high temperature. The flowchart from the planning section suggests targeting LoG4-5 on the flood prone blocks, but LoG1 on the other blocks. Soils have infiltration capacity of 2.5 in/hr. (Figure 05.02.11).



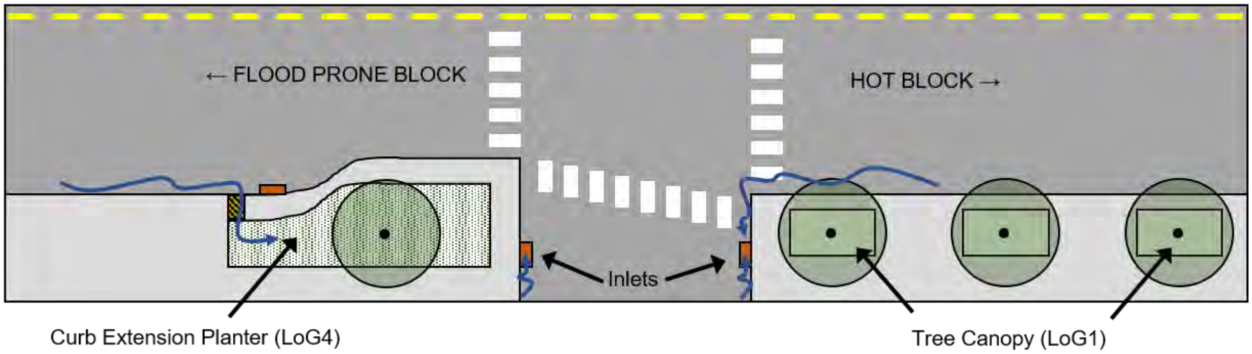
*Soils with low infiltration capacity preclude use of Level of Green 4. Geotechnical investigation required.

Figure 05.02.11: Flow chart for Case Study 3, with LoG4 and LoG1 as the target highest St to include on two different blocks of the project

Alternative 1 (Figure 05.02.12a) includes using the target LoG for each block: Curb Extension Planters on the flood prone blocks, and Tree Canopy on those that experience high temperature. Even though drainage infrastructure is present, Curb Extension SCMs without underdrains (LoG4) are selected for the flood prone blocks because soils are conducive for infiltration and because the curb extension will make pedestrian crossing safer. Tree Canopy SCMs (LoG1) are selected for the hot blocks to maximize shade and maintain space in the amenity zone for pedestrian traffic.

Alternative 2 (Figure 05.02.12b) includes both LoG4 and LoG1 SCMs on all blocks of the project. This plan makes for a unified streetscape across the project and provides the three benefits of stormwater flood control, heat mitigation, and pedestrian safety throughout the entire project corridor.

(a) Alternative 1: Single Level of Green



(b) Alternative 2: Multiple Levels of Green

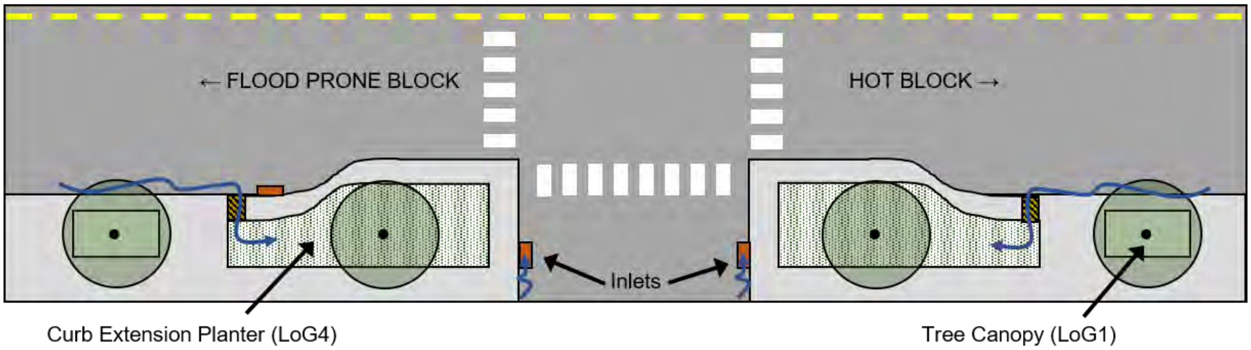


Figure 05.02.12: Alternatives for Case Study 3 using (a) one and (b) multiple Levels of Green on each block

03 - DESIGN

As a companion to the planning section, the Design section is intended to provide an overview of the application of the Levels of Green by City staff and consultants during the design process for projects in the public realm. This section also reflects the lessons learned through the application of Green Infrastructure in the City of Denver over the last decade.

03.1 - SITE CONTEXT

The character and context of the project site and adjacent land uses should be a critical consideration for designers as they consider the existing and future context and planning objectives of the SCMs surroundings and adjacent development. The following are some examples of contextual considerations:

EQUITY, CULTURE, AND ARCHITECTURAL CONTEXT

Special consideration should be given when designing SCMs in communities that are underserved and in those with unique and significant tradition embedded in the character of the area. Design should complement this character, and work towards providing an unbiased level of quality in the infrastructure and resulting benefits.

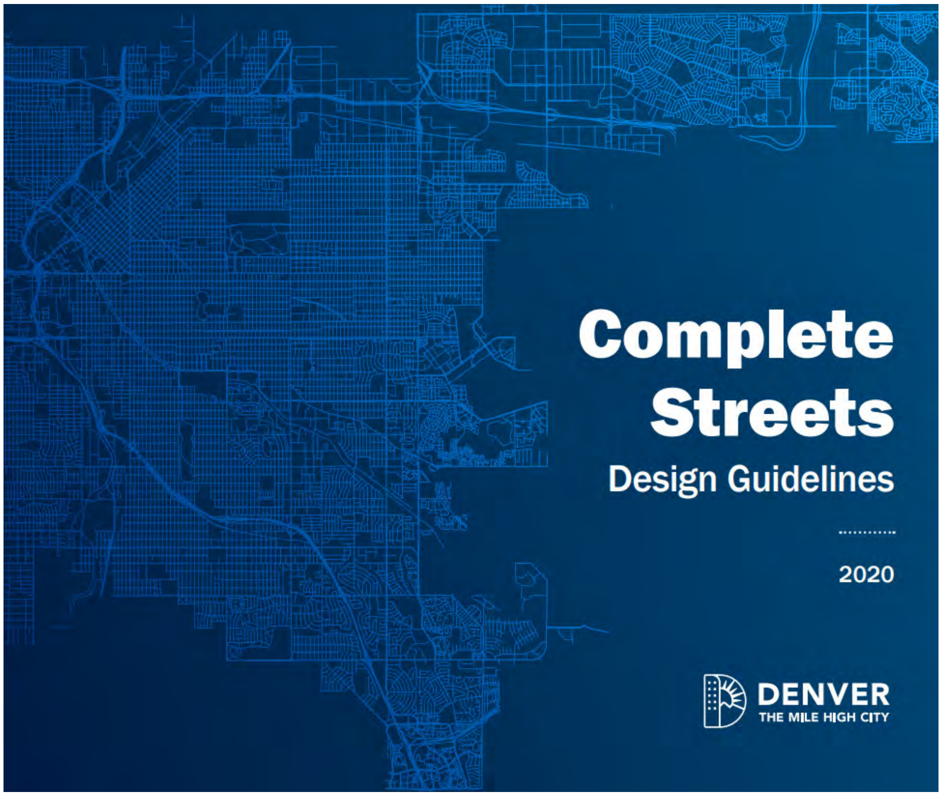
SCMs should be designed to complement the aesthetic and programmatic characteristics of nearby buildings, structures, and structured landscapes. Designers should prioritize material choices, scale, and forms that complement the surroundings when considering the aesthetic design of SCMs. Appropriate consideration should also be given to the current and desired future uses and programming of the surrounding areas. Evaluate opportunities to integrate interpretive/educational, interactive, and recreational features, such as trails, when projects are located in or around unique settings such as institutions, historical/special districts, or when adjacent to open spaces/parks.

STREET TYPOLOGY

As discussed in Blueprint Denver, streets can better accommodate the needs of all users when the design of the street takes into consideration the needs of the surrounding land-use and character. Denver's recently released *Complete Streets Design Guidelines* builds upon this approach and establishes and considers the uses and activities along the street edge in balance with travel demands. Denver's 16 street types can be found here, along with guidance on how green infrastructure can be implemented within each street typology.

The Green Continuum: Streets was specifically designed to provide greater flexibility and opportunity to implement green infrastructure within the various street typologies and

Figure 05.03.01: RiNO Park Water Quality Facility; Source WENK Associates



Complete Streets

Design Guidelines

2020

DENVER

THE MILE HIGH CITY

Figure 05.03.02: Cover for the Denver Complete Streets Design Guidelines (2020)

complement adjacent land uses and modes. By implementing both the strategies in the *Complete Streets Design Guidelines* and this document, Denver can achieve its vision of a more complete multimodal transportation system with an emphasis on safety, moving people, and creating attractive, sustainable public spaces.

03.2 - SITE EVALUATION & REPORTING

This section highlights necessary reports and plans required to review and assess SCM design.

TOPOGRAPHIC SURVEY

A full civil survey will be required to complete the design regardless of the Level of Green. The extent of the survey should encompass all of the drainage basins identified in the preliminary drainage analysis (Section 03.3). It will be advantageous to increase the density of survey points that are relevant to the SCM design. These include flow line elevations, top of curb, and top of walkway elevations near the proposed SCMs; road crown elevations especially through intersections; and any additional points needed to verify the divides of the drainage basins identified during the preliminary hydrologic analysis.

FLOODWAY CONSIDERATIONS

If any part of a project is located in a floodway any fill and above-grade improvements will require a hydraulic analysis to show the project will not raise Base Flood Elevations or adversely impact adjacent properties.

Any rise in Base Flood Elevations will require submission of a Conditional Letter of Map Revision (CLOMR) and Letter of Map Revision (LOMR) to FEMA. FEMA's review of the CLOMR can add several months to the project design timeline. Denver's floodways are mapped on the MapIt GIS data portal, and more information can be found in the *Denver Drainage Design and Technical Criteria Manual*.

SUBSURFACE UTILITY ENGINEERING (SUE) AND UTILITY RELOCATION PLANS

Projects that disturb the earth to a depth greater than 2 feet will be required to complete a Subsurface Utility Engineering (SUE) Plan. Most projects with LoG SCMs will trigger this requirement. Shallow SCMs without trees may be exempt.

The design constraints and considerations posed by surface and subsurface utilities are discussed in the following sections. Utilities should be addressed to the maximum extent practical by adjusting the site plan during the concept design phase. The utility relocation plan is an opportunity gather additional information and formerly address any constraints

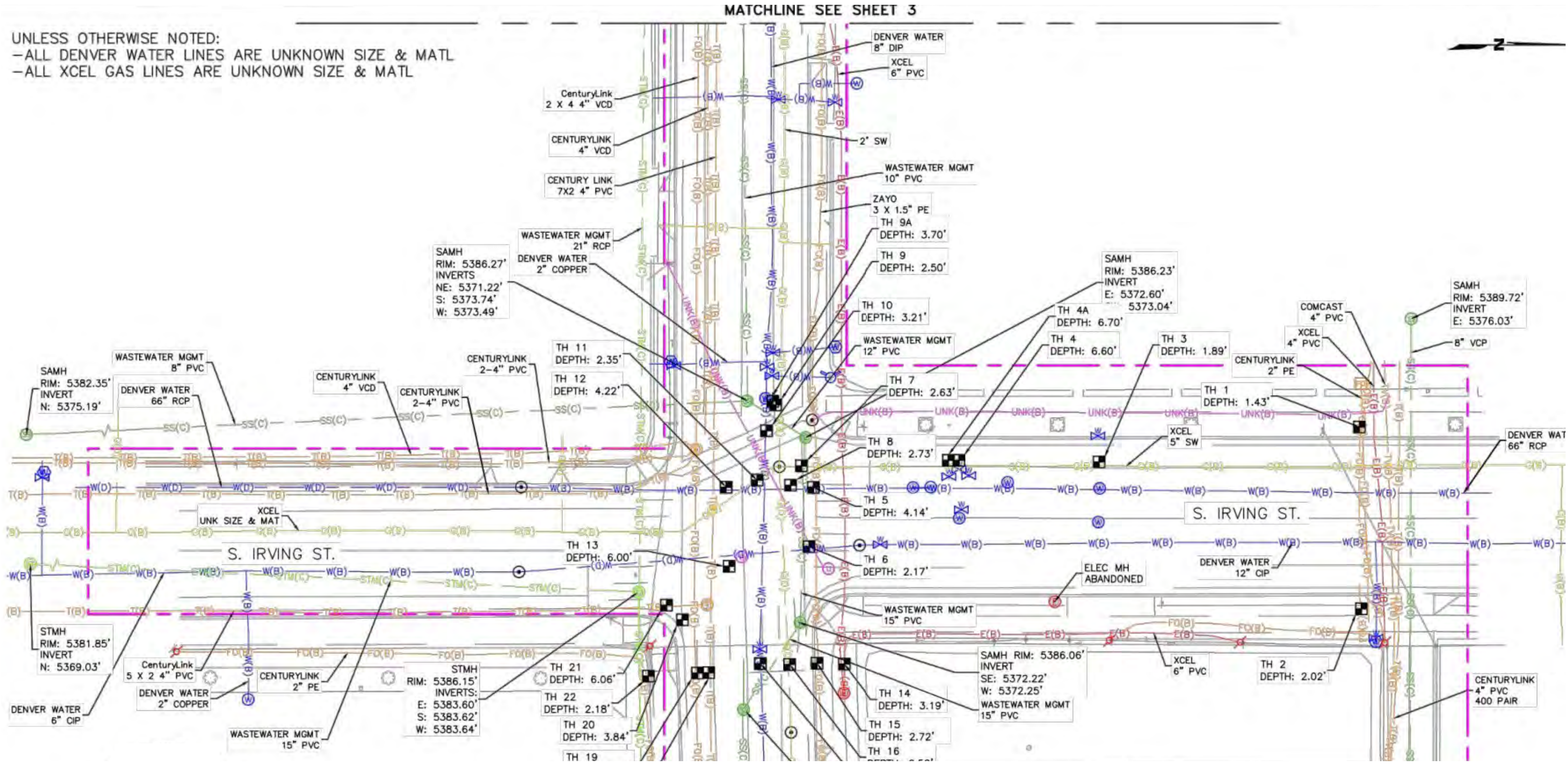


Figure 05.03.03: Example of Subsurface Utility Plan - (Kentucky & Irving Intersection, 2021)

that cannot be avoided.

GEOTECHNICAL INVESTIGATION

A geotechnical investigation and report will be required for most right-of-way projects. This investigation should include a bore hole at all potential SCM locations to characterize soil classification which has impacts for hydraulic function and plant health. It should also include results from tests that characterize the hydraulic conductivity at a depth equal to the interface of the bottom of the SCM and the native subgrade at the location of all potential LoG 3-5 SCMs. The tests can either be in-situ bore hole infiltration tests or laboratory hydraulic conductivity tests, as deemed appropriate by the geotechnical investigators. The test results should characterize capacity for deep infiltration, which is especially important for LoG4 SCMs.

ENVIRONMENTAL INVESTIGATION REPORT, MATERIALS MANAGEMENT PLAN (MMP), AND GROUNDWATER DISCHARGE

Environmental investigation and an MMP may be required prior to soil disturbing activities, depending upon site history and project scope. The Denver Department of Public Health and Environment Division of Environmental Quality should be contacted to assist with that determination. If soils will be exported off site, as might be expected with many projects but especially LoG 4-5, soil testing will be required to facilitate offsite reuse or disposal. It is unlikely that dewatering will be required given the vertical depth below ground surface of these SCM designs. If dewatering is necessary, additional steps will be required to allow for off site disposal or discharge to surface water.

TRAFFIC ENGINEERING PLAN

Projects that disturb or reconstruct the curb and gutter will require a Traffic Engineering Plan submitted to Denver Development Services. This will likely be required for LoG 3-5 SCMs, and some LoG 1-2 SCMs. If bumpout LoG 3-5 tools are used, it is important to consider whether the intersections meet the standards for turning of buses per RTD standards and fire trucks per Denver Fire Department.

03.3 - HYDROLOGIC ANALYSIS AND SIZING

DESIGN AND SIZING

If a project has a regulatory requirement for runoff water quality control, then the stipulations of the permit must be considered through the design process. LoG4-5 SCMs are designed to store and treat the water quality capture volume (WQCV), but lower LoG SCMs can also be used to help meet regulatory requirements by reducing impervious area and minimizing directly connected impervious area. This can result in smaller or fewer LoG4-5 SCMs needed to store the WQCV. This process of “Runoff Reduction” is explained in Volume 3 of the Mile High Flood District (MHFD) Criteria Manual. The MHFD-Detention excel spreadsheet can be used to calculate reductions in WQCV through minimizing directly connected impervious areas with LoG1-3 SCMs.

Projects without a regulatory requirement should maximize the area tributary to the SCMs to the extent that is practical and appropriate for each Level of Green. For projects prioritizing LoG 1-2 SCMs, this means maximizing the walkway zone area that is tributary to the SCMs. For projects prioritizing LoG 3-5 SCMs, this means maximizing all of the area identified during the preliminary drainage mapping that

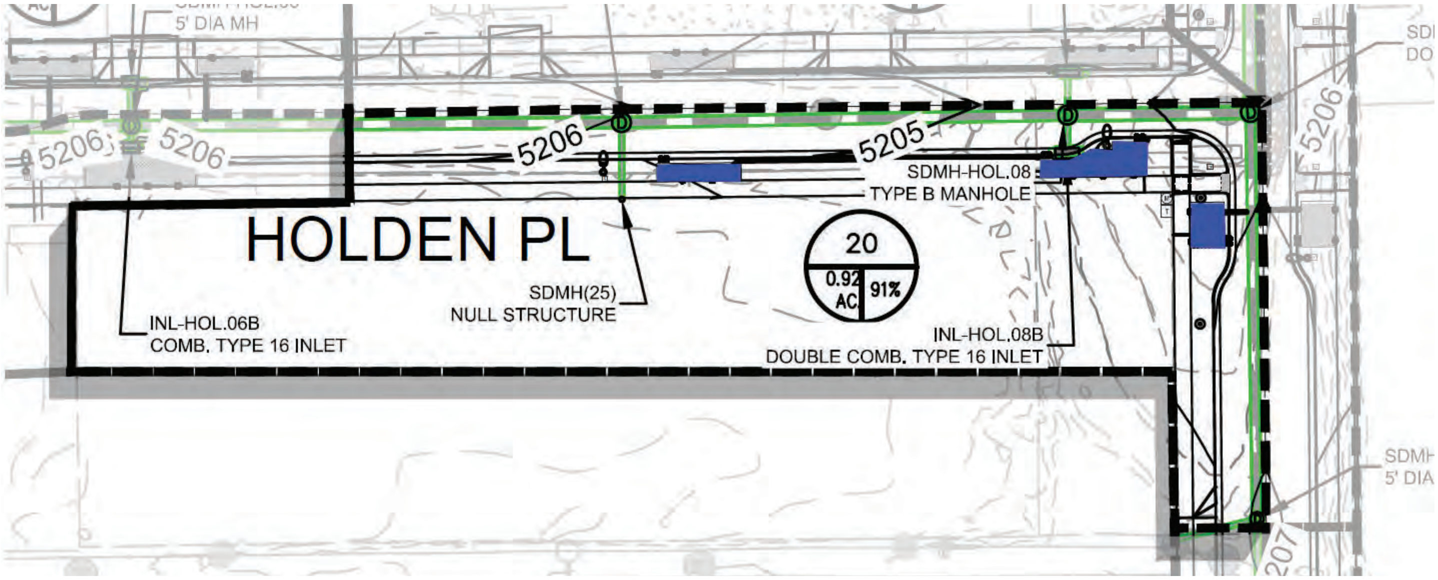


Figure 05.03.04: Sun Valley Basin Diagram - Each SCM should include tributary basin data

is tributary to the SCMs.

Designers should identify the range of alternatives for the outflow of stormwater from the SCM that is not infiltrated to subgrade. For LoG 1-3 SCMs, overflow can be routed to the street after confirming that the existing storm drainage network provides sufficient conveyance. For LoG 4-5 SCMs, underdrains can be used to convey outflow to the underground storm sewer system directly by tying into nearby manholes or laterals. Running underdrains long distances (>100 ft) or beneath streets should be avoided as this may add significant cost to the project. LoG 4-5 SCMs can also overflow on to the street during large events, again after confirming there is sufficient drainage infrastructure downstream to convey flows.

SCMs that are designed to collect runoff from the streets (such as LoG3-5) should not be located directly downstream of a storm system inlet as this will pull flow off the street before it enters the SCM. Rather, locate LoG3-5 SCMs just upstream of storm sewer inlets. These are typically topographic low points and often found at street intersections. Intersections also present an opportunity to use SCMs that bump out into street as they can have larger footprint areas and provide traffic calming and additional shade for bikers and pedestrians.

The preliminary drainage map should be used and refined to identify the direct tributary area to each candidate SCM location. For LoG 1-2, this will typically be the adjacent walkway and some of the adjacent parcel. For LoG 3-5 SCMs, this will entail half of the right-of-way and large areas of the adjacent parcels.

Designers should evaluate configurations of SCM's that meet the run-on ratio design guidelines. There are practical limits to the footprint given the maximum length guidelines, limited space, and conflicts in the right-of-way. For LoG 4-5 SCMs, compute the WQCV from the SCM's direct tributary area following the MHFD criteria manual. The surface storage and media depth should be adjusted to meet the volume storage requirement of the Level of Green, however the depths must stay within the ranges in the guidelines.

The process of siting a SCM, mapping it's direct tributary area, computing the WQCV (if applicable), and choosing the footprint area and depths will be an iterative process where the location and design of the candidate SCM is altered to meet the design guidelines.

PRELIMINARY DRAINAGE MAPPING

Locate stormwater drainage infrastructure including all inlets, manholes, laterals, and main lines using geospatial data, aerial imagery, and Google Street View. Elevation contours should be combined with the information on storm drainage, curbs and gutters, road crowns, and rooftop downspouts to understand drainage patterns in the right-of-way and the adjacent parcels. Field visits, especially during rain events or snow melt, are recommended if there is uncertainty about drainage patterns. If topographic survey data is available, it should be used in the analysis although it is not required.

The outcome of the hydrologic analysis should be a map of the drainage basins that encompass the entire project area and the area draining into the project area. There should be at least one basin mapping the area tributary to each stormwater inlet. If the project area has no inlets, map the area tributary to each corner of all intersections.

03.4 - TRANSPORTATION CONSIDERATIONS

PEDESTRIAN ACTIVITY AND FLOW

Pedestrian activity is an important consideration in designing SCMs. Locations with high pedestrian traffic, like a café or storefront, may benefit greatly from a reduced SCM footprint to reduce potential conflicts. In areas with limited ROW width narrower SCMs may be more appropriate to allow for more space for pedestrians.

The directionality of pedestrian movement is also important to consider. Locations with street-side parking and high turnover, or where pedestrians are crossing the amenity zone or tree lawn to local businesses, should consider how pedestrians

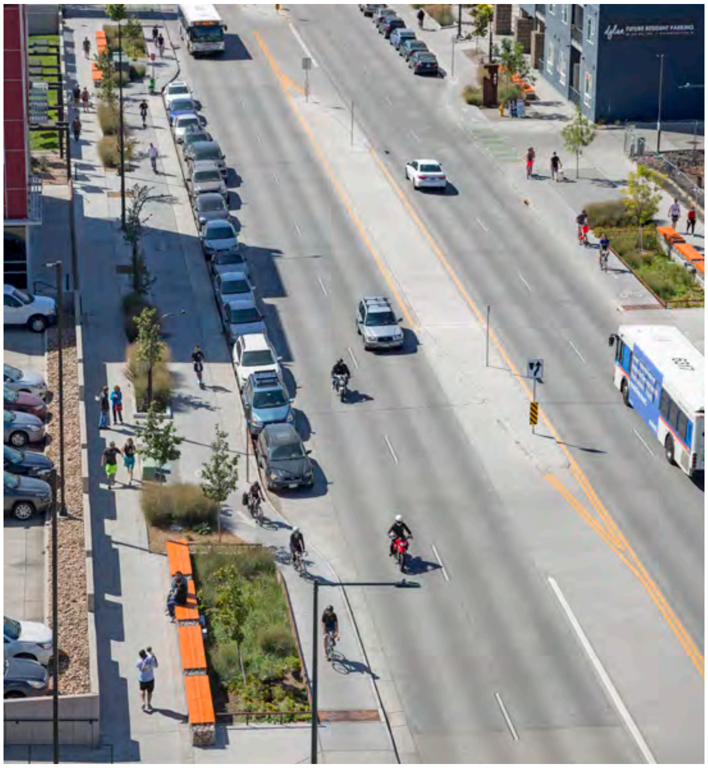


Figure 05.03.05: Brighton Blvd. Pedestrian and Bicycle Zones

step out of vehicles and cross the zone. In these highly active areas LoGs which are more compact are appropriate in order to prioritize pedestrian movement. Where pedestrian movements are more linear and do not cross the amenity zone (such as areas with no parking adjacent to the curb), this is less of a concern.

PARKING

Street-side parking generates additional considerations for placing SCMs. If parking is next to a potential SCM location, consider pedestrian activity and flow (described above), step-out accommodations, and access for associated facilities (i.e. meters, pay stations, etc). Additionally, it may be a priority to preserve street-side parking in commercial areas and therefore SCMs located behind the original curb line may be preferred.

If the right-of-way has sufficient space to incorporate step-out zones and walkways between the SCMs, as is the case in industrial and some residential areas, there may be an opportunity to utilize a wider variety of SCMs. In these cases, SCMs of all levels can be effectively implemented together in linear series along a roadway.

WALKWAY AND “AMENITY ZONE”

Because SCMs are frequently located directly adjacent to walkways or between buildings and roadways, SCM designs should consider right-of-way characteristics, and the appropriate widths of walkways and amenity zones required for people to comfortably use them. Areas with high volumes of pedestrian activity or café/commercial uses may require wider walkways than the minimums required by code; alternatively, some areas may have overly widened sidewalks which could be narrowed to allow for more vegetated landscape area if lower pedestrian and amenity use is expected.

BIKE LANES

SCMs on the Green Continuum can improve bike lane design by providing shade, calming vehicle traffic, and reducing conflicts between pedestrians, bicyclists, and automobiles. If a bike lane is adjacent to an SCM, the orientation and directionality should be considered similarly to pedestrian flow. If the bike lane is within the pedestrian realm, or sharing the walkway, the width of the SCM may need to be limited.

If there is a bike lane within the street, adjacent to the curb without street-side parking, this could present an opportunity to use longer SCMs because frequent crossing of the SCM by pedestrians would not be anticipated. Additionally, step-out zones may not be required in this case allowing for a wider SCM design. If separating the bike lane and pedestrian realm is desirable for safety reasons, designers should consider ways for SCMs to aid in buffering the two uses.

If the bike lane is oriented between traffic and street-side parking, similar considerations should be made as those with street-side parking (see section below) as this configuration tends to be in areas where pedestrians cross the landscape area with frequency. Designers should consider how bike racks could be integrated in spaces between SCMs and amenity access.

BUS STOPS

Designers should coordinate with RTD if SCMs are planned near existing bus stops. An important considerations when designing near bus stops are preserving space for passenger loading and protecting passengers from tripping. Using SCMs with tree grates and permeable paving can preserve area for loading and unloading passengers. SCMs that are depressed and located near bus stops should be carefully sited, and special attention should be paid to the design of edge barriers and grade control components. In some cases bus stops may be relocated in coordination and with the approval of RTD.

ROAD CLASS

In addition to controlling the pedestrian, parking, and bike lanes considerations explored above, road class is also an important consideration for designing SCMs because higher volume classifications such as collector or arterial roads can be expected to accumulate particulate matter at a faster rate. This may result in SCM designs that have larger, more heavily armored forebays and will require more frequent maintenace.

ROAD OWNERSHIP

Whether the right-of-way is owned by the city has important impacts to the project and design of the facilities. For example, installing SCMs on state-owned roads will require intergovernmental agreements at the onset of the project to determine shared project priorities, funding arrangements, design criteria and metrics, ownership, and maintenance responsibilities for the SCMs.

03.5 - SURFACE CONFLICTS

LIGHT POLES AND SIGNS

Surface infrastructure, such as traffic signs and light poles, should be avoided when locating SCMs. If locational conflicts cannot be avoided, light poles and signs may be embedded directly into a SCM. If embedded in the facility, ensure that all electrical conduits are below grade and water-tight. In additional to locational considerations, all light poles and signage must follow Denver's Office of the City Forester (OCF) requirements for spacing from trees and should take into account future growth and final canopy size.

TREE COVERAGE AND SPECIES

Trees are a critical component in a systemic approach to reducing runoff via precipitation interception and increased infiltration, improving urban forest species diversity, and in the creation of shade to help mitigate the effects of urban heat islands. Strong consideration should be given to the quantity and quality of the surrounding project area's existing tree canopy when designing the vegetative aspects of SCMs. Designs should take a balanced approach to preserving high-quality mature trees and introducing additional trees in order to increase the overall benefits. If a high-quality tree canopy exists adjacent to the project or outside of the ROW, then consideration of limiting impact to the existing trees should be given when attempting to incorporating lower height vegetation.

03.6 - SUBSURFACE CONFLICTS

Understanding the location of utilities is important for locating SCMs. If the location includes surface utilities (i.e., pull boxes, meters, fire hydrants, vaults, cabinets, etc.), consider utility depth and extents. SCMs should not be located above underground utility mainlines. If it cannot be avoided, SCMs can be located above some service lines or laterals if coordinated with the utility. Rather than relocating service and lateral lines, they should be sleeved if already located below the bottom of the SCM or deepened and sleeved if shallow and in conflict with the SCM construction. If this is not possible, then services lines and laterals can be relocated to ensure approvable clearances.

If there are shallow buried utilities within the project area LoG 1, 2, and 3 SCMs can be placed above these utilities in some instances or adjusted horizontally more easily compared to LoG 4 and 5 SCMs. LoG 4 and 5 require some vertical clearance for underdrains and storage and may connect to stormwater infrastructure. If there are many surface utilities in the project area an LoG 4 or 5 SCM can utilize a smaller horizontal footprint but may need more vertical clearance.

Specific conflicts for consideration are as follows:

- Sanitary - SCMs should not be placed over sanitary sewer mainlines unless coordinated with Denver Wastewater or Metro.
- Water Supply – Denver Water should be consulted when there are utility conflicts.
- Fire Hydrants - A five-foot clear space shall be maintained around the circumference of fire hydrants, except as otherwise required or approved.
- Gas – Xcel should be consulted when there are utility conflicts.
- Telecomm – Fiber optic utilities are often buried shallower than other utilities which make conflicts with all SCMs more likely.
- Utility potholing and bore pits are not permitted within the footprints of SCMs.
- Trees & Vegetation - Trees shall be located with clearances to structures, poles, signs, and both underground and overhead utilties as defined by the OCF
- Required irrigation will need to be installed so as to not conflict with other subsurface utilities.

In addition to potential utility conflicts all SCMs and their components must meet applicable city rules & regulations and Transportation Standards. There are clear zone requirements throughout the right-of-way that may conflict with the design approaches in these guidelines that will require coordination with review staff to be approved.

03.7 - OPERATIONS & MAINTENANCE

All infrastructure, in particular living infrastructure, requires maintenance. A detailed maintenance plan should be developed during the design phase and signed off on by the city's green infrastructure operations and maintenance team. The maintenance plan should detail both the routinely scheduled activities and those that are required after a large storm event. Maintenance activities will require regular soil and plant layer maintenance to ensure a healthy vegetation system that supports growth, infiltration, storage, and/or the pollutant removal function intended within each Level of Green.

Maintenance responsibilities will generally increase as the complexity of the LoGs increase but should not be the driving factor behind the selection of an LoG. All Levels of Green will require watering or irrigation care, trash collection, weed control, and occasional pruning. Levels of Green 3, 4, and 5 will require additional inlet and forebay inspection and maintenance. Some LoG 4's and all LoG 5 will require overflow and underdrain inspection and maintenance to prevent ponding or potential flooding. Successful maintenance activities will result in green infrastructure facilities that function as designed and are attractive community amenities that optimize maintenance efforts and resources long-term.

ENDNOTES

1 CDPHE. SEPARATE STORM SEWER SYSTEMS (MS4s) FOR THE CITY AND COUNTY OF DENVER - Draft 2019 Renewal; 2019.

2 Matrix Design Group. City and County of Denver S*tormwater Quality Prioritization and BMP Opportunity Analysis*; 2015.

3 City and County of Denver. *City & County of Denver Storm Drainage Master Plan*; 2019.

Appendices

01 - BMP PLANT LISTS

Choosing the right vegetation in each level is critical for long-term plant health and survivability. Level of Green 1 and 2 offer the best opportunity to plant pollinator gardens or water-wise, xeric gardens. Level of Green 3 requires a plant palette that can tolerate some minor inundation of water followed by periods of drought. LoG 4 & 5 will require plants approved for use in stormwater facilities as illustrated in the Ultra-Urban Green Infrastructure Guidelines Approved Species List. Regardless of the Level of Green, a landscape architect should be an integral part of the design team to help with the proper plant selection while integrating good urban design. A small list of plants is presented below based on research, experience and use in Denver, but is by no means an exhaustive of plants suitable for use in the various levels of green. Plants are organized by common name and then followed by the botanic name in italics.

LEVEL-OF-GREEN 1 AND 2

POLLINATOR GARDENS

In 2016 Mayor Hancock signed the National Wildlife Federations Monarch Pledge to help create sustainable practices that support the increase of native pollinating insects, which is important to the health and beauty of Denver. Since then, Denver Parks and Recreation has worked to increase the amount of pollinator gardens throughout the city. Level of Green 1 and 2 can help meet this goal by selecting plants that provide a variety of nectar and pollen sources throughout the growing season.


Figure 06.01.1 : Bee pollinating a flower

Colorado State Extension recommends the following plants for the various seasons:

EARLY-SEASON

- Nodding onion – *Allium cernuum*
- Winecups – *Callirhoe involucrata*
- Sulphur flower – *Eriogonum umbellatum*
- Wallflower – *Erysimum spp.*
- Prairie smoke – *Geum triflorum*
- Blue Flax – *Linum lewisii*
- Blue mist and firecracker penstemon – *Penstemon eatorii and P. virens*
- Pasque flower – *Pulsatilla patens*
- Penstemons (many native and cultivar options, check with local nursery)
- Yarrow – *Achillea millefolium*
- Serviceberry – *Amelanchier alnifolia*

MID-SEASON

- Asters (many native and cultivar options, check with local nursery)
- Pearly everlasting – *Anaphalis margaritacea*
- Showy milkweed – *Asclepias speciosa*
- Harebells – *Campanula rotundifolia*
- Blanket flower – *Gaillardia aristata*
- Salvias (many native and cultivar options, check with local nursery)
- Lead Plant – *Amorpha canescens*
- Flowering trees including willows, black locust, linden and honey locust

LATE-SEASON

- Blue Giant Hyssop – *Agastache foeniculum*
- Rocky Mountain bee plant – *Cleome serrulata*
- Plains Coreopsis – *Coreopsis tinctoria*
- Common sunflower – *Helianthus annuus*
- Hairy False Goldenaster – *Heterotheca villosa*
- Goldenrod – *Solidago spp*.
- Rabbitbrush – *Chrysothamnus nauseosus*
- Chokecherry – *Prunus virginiana*

Source: Colorado State University

https://extension.colostate.edu/topic-areas/insects/creating-pollinator-habitat-5-616/

WATER-WISE/XERISCAPE GARDENS

In 1981, Denver Water coined the term xeriscape which combined the words landscape and the Greek word 'xeros' which means dry. Xeriscape landscapes promote water efficiency by using plants that are native and adaptable to Colorado's semi-arid climate and soils. Native and adapted non-native plants are more resistant to pests and help to restore lost habitat and biodiversity. Key design elements include grouping plants with similar water and light requirements while using plants with different heights, colors and bloom times. Common trees, shrubs and perennials from Denver Water's low maintenance and xeriscape plans are listed below that are suitable for use in xeric landscapes.

PERENNIALS:

- Dragon's Blood -- *Sedum spurium "Dragon's Blood"*
- English Lavender-- *Lavandula angustifolia "Munstead"*
- Flame Grass -- *Miscanthus sinensis "Purpuranscens"*
- Moonbeam Coreopsis -- *Coreopsis verticillata "Moonbeam"*
- Paprika Yarrow -- *Achillea millefolium*
- Pine Leaf Penstemon -- *Penstemon pinifolius*
- Russian Sage -- *Perovskia atriplicifolia*
- Snow in Summer -- *Cerastium tomentosum*
- Coronado Hyssop – *Agastache aurantiaca*

GRASSES:

- Blue Fescue -- *Festuca ovina glauca*
- Dwarf Maiden Grass -- *Miscanthus sinensis "Yaka Jima"*
- Flame Grass -- *Miscanthus sinensis "Purpuranscens"*
- Indian Grass -- *Sorghastrum nutans*
- Karl Foerster Grass -- *Calamagrostis acutiflora "Karl Foerster"*
- Tall Blue Rabbit Brush -- *Chrysothamnus nauseosus albicaulis*
- Switch Grass -- *Panicum virgatum*

SHRUBS:

- Cutleaf Sumac – *Rhus typhina "Laciniata"*
- Hancock Coralberry – *Symphoricarpos x chenaultii 'Hancock'*
- Leadplant -- *Amorpha canescens*
- Shrub Cotoneaster – *Cotoneaster lucidus*
- Spanish Gold Broom – *Cytisus purgans*
- Serviceberry -- Amelanchier alnifolia
- Vanhoutte Spirea -- *Spiraea x vanhouttei*

TREES

- Gamble Oak – *Quercus gambeii*
- Goldenrain Tree – *Koelreuteria paniculata*
- Rocky Mountain Maple – *Acer glabrum*

Source: Denver Water

https://www.denverwater.org/residential/rebates-and-conservation-tips/remodel-your-yard/xeriscape-plans

PLANT SELECT

Many of the plants listed, plus many others, can be found through Plant Select. Plant Select is a non-profit collaboration between Colorado State University, Denver Botanic Gardens, and professional growers and horticulturalists designed to make plants available that thrive in the high plains and intermountain region. According to Plant Select plants chosen must flourish with less water, thrive in a broad range of conditions, be habitat-friendly, be unique, resist disease and insects, provide long last beauty, and be non-invasive. A full list of Plant Select plants can be found at https://plantselect.org/plants/our-plants/.

LEVEL-OF-GREEN 3

Level of Green 3 landscapes are shallow landscapes designed to have water flow through them and may temporarily store small amounts of water. LoG 3's should not experience the same level of inundation as the latter 4 and 5 levels but do need to be able to tolerate some amount of 'wet feet'. For this reason, perennials, ornamental grasses and shrubs were selected that can tolerate both wet and dry soil moisture levels.

PERENNIALS

- Blanket Flower – Gaillardia aristate
- Black Eyed Susan -- Rudbeckia hirta
- Coneflower – Echninacea sp.
- Denver Gold Columbine – Aquilegia chrysantha
- Goldenrod – Solidago rugosa
- Obedient Plant – Physostegia virginiana
- Prairie Coneflower -- Ratibida columnifera
- Rose Swamp Milkweed – *Asclepias incarnata*
- Wild Bergamot – *Monarda fistulosa*
- Western Hops -- Humulus lupulus

GRASSES

- Indian Ricegrass -- *Oryzopsis hymenoides*
- Prairie Sandreed -- *Sporobolus cryptandrus*
- Ruby Muhly Grass – *Muhlenbergia reverchonii*
- Switch grass – *Panicum varigatum*

SHRUBS

- False Indigo -- *Amorpha fruiticosa*
- Littleleaf Mountain Mahogany -- *Cercocarpus intricatus*
- Sand Cherry -- *Prunus besseyi*

TREES

- Bur Oak -- *Quercus macrocarpa*
- Hackberry – *Celtis occidentalis*
- Honey locust – *Gleditsia triacanthos*
- Woodward Columnar Juniper – *Juniperus scopulorum 'Woodward"*

Sources: Colorado Stormwater Center & High-Country Gardens

http://stormwatercenter.colostate.edu/wp-content/uploads/2020/04/Colorado-Rain-Garden-Guide-2017-8-8.pdf

https://www.highcountrygardens.com/gardening/build-a-rain-garden#:~:text=Best%20Plants%20For%20A%20Rain%20Garden&text=These%20include%20Aster%2C%20False%20Indigo,(Zepheranthes)%20and%20ornamental%20grasses

LEVEL-OF-GREEN 4 AND 5

Plant palettes in Level of Green 4 and 5 have been well researched as part of the development of the *Ultra-Urban Green Infrastructure Guidelines*. Those plant lists are available in the UUGIG document located on the Office of Green Infrastructure website located at http://denvergov.org/greeninfrastructure.

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